A Procedural Guide
for Technical Implementation
of the FORECAST Methods
of Task and Skill Analysis

by Edgar L. Shriver, C. Dennis Fink and Robert C. Trexler

TRAINING METHODS DIVISION
HUMAN RESOURCES RESEARCH OFFICE
The George Washington University
Post Office Box 3596
Washington 7, D. C.

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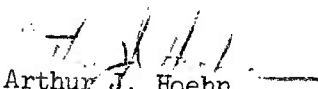
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SUBJECT: Technical Implementation of the FORECAST Methods of Task
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1. Inclosed for your retention is an informal report written by
Shriver, Fink and Trexler and titled "Technical Implementation of the
FORECAST Methods of Task and Skill Analysis."

2. This document is a follow-up to an earlier formal report,
"Determining Training Requirements for Electronic System Maintenance:
Development and Test of a New Method of Skill and Knowledge Analysis,"
by Edgar L. Shriver, HumRRO Technical Report 63, June 1960. The formal
Technical Report briefly described the task analysis and training
techniques developed in HumRRO Task FORECAST. However, it was not
possible in the earlier report to give detailed guidance on how to do
the analyses and how to use the training techniques. The present informal
report is designed to fill this need. Thus it should be useful to those
who want to more thoroughly examine the FORECAST methods and to those who
are interested in applying the methods.

3. We would appreciate any comments which you may wish to make.
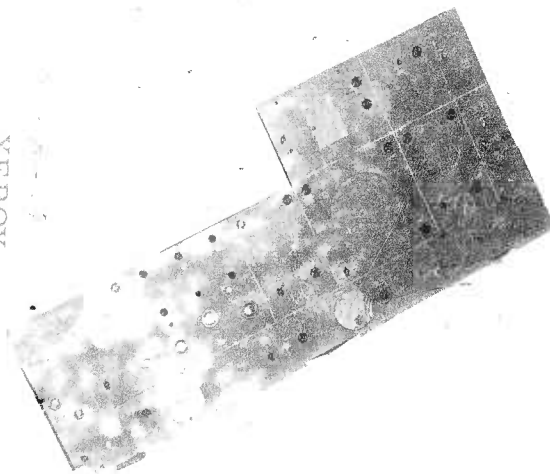
Arthur J. Hoehn
Director of Research

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FORECAST

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FOREWORD

The methods of task and skill analysis described in this procedural guide were developed during research in HumRRO Task FORECAST, which is directed toward developing means for accurately forecasting the training demands imposed by new electronic weapon systems.

Methods for forecasting training needs for a guided missile system were constructed and experimentally evaluated in Subtask FORECAST I. This phase of the research is described in HumRRO Technical Report 63, <u>Determining Training Requirements for Electronic System Maintenance: Development and Test of a New Method of Skill and Knowledge Analysis</u>, by Edgar L. Shriver, published in June 1960. The system of analysis was modified and refined in FORECAST II, in which transfer of training, increased proficiency, and equipment-minimizing effects of the method were studied. A study of the application of the FORECAST concepts to equipment other than that on which the methods were developed was also conducted; and these procedures have now been incorporated in the IMPROVED NIKE HERCULES HIPAR course at the Ordnance Guided Missile School in conjunction with FORECAST III.

It is believed that the procedures described herein can serve as a basis for further implementation or development of this type of analysis by personnel working in this technical field.

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INCREASING TROUBLE SHOOTING PROFICIENCY
BY MEANS OF THE **FORECAST** SYSTEMS-ANALYSIS APPROACH

INTRODUCTION

The objective of Task FORECAST of the Human Resources Research Office is to develop methods for accurately forecasting the training demands imposed by new electronic weapon systems. Making forecasts of training programs is not new to the Army. On the contrary, in the area of radar maintenance it is standard practice. The degree of accuracy of present forecasts is sufficient for electronic equipments as they currently exist. But with increasingly complex electronic systems, it is becoming very difficult to accurately forecast the skills and knowledges that the maintenance man must have in order to maintain these new systems. Task FORECAST is an attempt to provide methods of improving the accuracy of such forecasting. This manual is a description of the methods developed in the FORECAST research for that purpose.

It is recognized that if every repairman could be trained as a graduate engineer, repair proficiency probably would improve. Why should this be so? It is because an electronic system appears to be completely unstructured until it is understood in terms of the electronic events that occur within it.[1] Once the relation of the parts of a system to its functions is understood, the parts of the system become meaningful. They can be understood in terms of what they are for and what will happen if they malfunction. Such understanding enables a repairman to efficiently maintain and repair the system.

Unfortunately, with existing limitations in training time and human capabilities, training schools can not produce graduates who have the desired breadth of understanding of electronics. We can no longer assume that 30 weeks of electronics training will provide the skills and knowledges required of a repairman for the more complex systems. After such training, the repairman still does not have at his disposal all the information that he needs. It appears, then, that improvements in proficiency must come through increases in the accuracy of identifying the demands of a particular job, rather than through an across-the-board increase in all engineering skills and knowledges—at least during the first enlistment. It is this reasoning which suggests that a change in the

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[1] A general description of the functioning and conceptual structure of electronic weapon systems is given in Appendix A.

traditional forecasting approach is needed, if the proficiency of maintenance men is to be increased under present restrictions of time and human capacities.

It was reasoned that proficiency could be increased within existing limitations if more pertinent and better organized electronics information were made available, by some means, to the maintenance man. It was reasoned, also, that this information could be obtained by first arranging the parts of an electronic system on schematic diagrams in such a way that the inherent structure of the system could be more easily perceived in terms of trouble shooting. The structure could then be analyzed to determine the skills and knowledges required for the repairman to understand and employ it.

The traditional way, mentioned above, is to give the student a broad training in electronics so that he can use this knowledge to determine for himself the organization of the system. The FORECAST approach is to have experts organize the system on schematic and block diagrams, and teach the student how to use this organization to maintain and repair the system.

By first structuring the system from the standpoint of maintenance and then deriving training content in support of that structure, it is believed that training demands can be determined more accurately. If these determinations can be made from information about the system (such as schematic diagrams) available before the system is produced, the total process can be considered a forecasting tool.

This introduction has sketched the research problem undertaken by Task FORECAST. It serves also to outline the nature of the solution; that is, to organize the system rigorously and then determine the training demands imposed by that organization.

THE TROUBLE SHOOTING PROBLEM

<u>What Is the Job of Army Radar Maintenance?</u>

The job of Army radar maintenance is to accomplish all things necessary to keep radar systems operating within tolerance limits after they are owned by the Army. The maintenance job may be defined in terms of the following subjobs performed by maintenance men: (1) preventive maintenance, (2) repairs, (3) adjustments, (4) system modifications, and (5) trouble shooting. These jobs are accomplished with common and special test equipment.

In general, organizational maintenance is responsible for <u>preventive maintenance</u>, <u>adjustments</u>, and <u>trouble shooting</u> to the levels of <u>chassis</u> or <u>tube</u>. In doing this, <u>common</u> test equipment is used. Ordnance maintenance is responsible for all the above and, in addition, for <u>trouble shooting</u> to <u>parts</u> and replacement of parts, effecting repair of the system; in doing this both <u>common</u> and <u>special</u> (Ord 6) test equipment is used. Ordnance maintenance is responsible also for modifying systems in accordance with explicit instructions.

It is generally recognized that preventive maintenance and adjustments involve following rather routine instructions. In a somewhat

similar fashion, using the Ord 6 equipment necessitates following printed instructions on an Instruction Card (IC). System modifications also involve the ability to follow instructions in schematic form. Finally, the replacement of parts needed to complete repairs (after trouble shooting is accomplished) calls for only a certain amount of manual dexterity and soldering skill. In fact, the only subjob done by maintenance men that is not fairly routine is trouble shooting. This includes trouble shooting to chassis and tubes (organizational), and to parts (ordnance). It includes also the trouble shooting that must be accomplished when the routine Ord 6 "IC" does not direct the maintenance man to replace a specific part—but merely indicates a general area in which the malfunctioning part must lie.

This manual is concerned primarily with the trouble shooting problem. This does not mean that the other subjobs of maintenance have been ignored, but only that the amount of time now devoted to them is small and their content tends to be relatively routine. Changes in these subjobs would not have the impact of changes in trouble shooting procedures. Consequently, the FORECAST effort has been mainly directed toward trouble shooting, and this manual reflects that emphasis. It does not imply that a training program based on the FORECAST approach would ignore training in the more routine aspects of maintenance.

Trouble Shooting

The term trouble shooting means identifying the cause of an out-of-tolerance system output. In electronic equipment it is a process which involves the successive elimination, by interpretation of symptoms and measurements, of those parts of the system that are not causing the trouble. Using the electronics information at his disposal (e.g., signal flow), the repairman makes a series of deductions which progressively narrow the source of the malfunction to one or more out-of-tolerance parts (e.g., resistor, capacitor, cable). Replacement or adjustment of these parts constitutes repair of the system.

Need for Increased Trouble Shooting Proficiency

Making deductions from symptom information about the condition of electronic parts can be very easy or very difficult, depending on the circuits involved. In some cases these deductions can be so difficult that even the person who designed the circuit has trouble in accurately deducing what parts may be defective.

Although Army electronics schools today devote 30 weeks to radar repair training programs, it is generally recognized that even this is too short a time for a repairman to acquire the fund of electronics knowledge that would enable him to make all the deductions necessary for locating all possible malfunctions of a radar system. It is true that sufficient knowledge for repairing a certain percentage of possible malfunctions is currently obtained by the repairman during his 30 weeks of training. The exact percentage is debatable. It is not the aim of Task FORECAST to provide exact data on this, but rather to develop a means whereby the graduate repairman can have more pertinent and

better organized electronics information at his disposal, and will thus be able to maintain a radar system even better than he does today.

Current Concepts of Trouble Shooting Training

Current trouble shooting training is based on the philosophy that, to trouble shoot a radar system, a repairman should have sufficient knowledge to be able to compute the correct value at every possible check point in the system. As a corollary to this, he should have the knowledge to enable him to determine the parts of the system that affect the values at every point.

This philosophy of training prescribes two principal types of electronics knowledge: basic electronics and system-specific electronics. The basic electronics deals with general electronics information, including general methods for computing circuit values. System-specific information is concerned with detailed circuit analyses which describe the theory of how the electrons flow through particular circuits to achieve the effects produced by those circuits. This provides a general background for determining the parts that affect readings at all points in the system. In addition to this electronics information, repairmen also are provided with some information on the probabilities that various types of parts will malfunction. From these knowledges the repairman is expected to draw the information required to determine which parts in the system are within tolerance and which are out of tolerance for any particular malfunction. It is unfortunate, but true, that students cannot learn enough of this general type of information in 30 weeks to apply it with maximum effectiveness to the job of system repair.

It is easy to see that this fundamental concept of electronics training is a desirable goal. And certainly, with sufficiently long training, enough general engineering electronics could be taught to substantially increase the accuracy of trouble shooting.

However, at the present time course length cannot be extended. In addition, training program success is somewhat limited by the aptitude of the trainees. Even men with intelligence substantially above average would require much longer than 30 weeks to learn all the electronics needed. Finally, there is the practical limitation of the three-year enlistment period for repairmen.

The FORECAST goal is to develop an approach that will increase the amount of pertinent electronics information available for the trouble shooting process without increasing the amount the repairman must memorize during training.

THE FORECAST SYSTEMS-ANALYSIS APPROACH

Organizing the System for Trouble Shooting

The Basic FORECAST Approach

As in the traditional philosophy of training, the FORECAST approach is concerned with the body of electronics knowledge from which trouble shooting deductions are made.

The important departure of the FORECAST concept from the traditional philosophy is in the means of selecting, generating, and organizing a particular body of knowledge and placing it at the repairman's disposal. It is this specific information which represents a more accurate estimate of training demands than does the traditional forecast of broad electronics knowledge. Thus the FORECAST procedures are unique not in producing a way to forecast, but rather in producing a set of specifications for forecasting more accurately. In addition to providing the specifications for selecting, generating, and organizing electronics knowledge, the FORECAST approach employs, as system analysts, experienced and especially competent repairmen, who use the specifications to produce the information needed for the trouble shooting process. It is by this means that accurate information is placed at the disposal of the repairman. These two points are the key to the FORECAST approach.

Let us first consider the question of selecting, generating, and organizing pertinent electronics knowledge. Of the different kinds of knowledge required for electronics maintenance, two are of prime importance: (1) what the measured values at various points in the system should be, and (2) what portions of the system affect the values measured at those points.

This type of knowledge is essential for trouble shooting because of certain peculiarities of electronic equipment. One peculiarity is that the values measured at different places in the system are affected by a widely varying number of parts. For example, a measurement at one point may be affected by 5,000 individual parts, while a measurement at another may be affected by only 100 parts, or 10 parts, or one. This fact makes it possible for a trouble shooter to narrow the malfunction to a specific part by a series of tests with successively less generality.

What measurement points must the repairman know about to do his job effectively? As has been stated, one traditional answer is that he must have the basic knowledge to determine or compute the correct value at every possible point in the system. This answer also implies that the repairman knows or is able to determine, the parts of the system that affect the values at every point.

The above answer is traditionally coupled with a trouble shooting procedure commonly known as "signal tracing." This procedure makes use of a general trouble shooting logic which states that when a stage has good signal inputs but one or more bad outputs, then the trouble must lie somewhere within that stage. This logic seems simple and straightforward, but its practical value has been limited because, in the traditional approach, the specific parts contained within the stage are never identified. It is easily seen that there is no need for this identification of parts within the traditional training philosophy; the repairman is expected to use his general and system-specific electronics information to deduce for himself what parts belong within each stage, as well as the value of the stage output. However, as has been pointed out before, repairmen cannot learn sufficient electronics in 30 weeks to be able to make all these deductions.

It is because of this limitation that the FORECAST approach uses certain procedures performed by electronics experts to determine in advance of any malfunction just what parts can affect a measurement made at the check point that defines the stage output. It can be established that particular parts, and only those parts, can affect a given reading, and that none of them can affect a measurement made at any point earlier in the signal flow. Through this analysis, appropriate check points throughout the system are identified, along with the tolerances for the measurement to be taken at each point. This knowledge allows the simple logic of trouble shooting to be a useful tool for the repairman. In this way, skills and knowledges appropriate for trouble shooting are selected and organized into a form that puts more pertinent information at the disposal of the repairman. The means for doing this are described in the next section.

In summary, the FORECAST analysis results in an organization of the system into a series of trouble shooting blocks having the purpose of making the traditional trouble shooting logic function infallibly—without error or ambiguity. This is accomplished through bringing the system and the logic into congruence through the FORECAST process of system analysis.

Setting the Limits of the Trouble Shooting Block

Trouble shooting logic is appropriately applied to linear chains in which the signal moves in one direction and can be traced along its path. However, the signal-flow logic can not be used to identify all individual malfunctioning parts because the path the signal follows is affected by auxiliary paths that are not directly in the signal flow. These auxiliary paths consist of groups of parts or small chains of parts that converge to produce desired alterations in the signal flow. A characteristic of these small chains is that the signal-flow information (measured at the point of convergence) does not always show which of a number of converging chains is causing the interruption in signal flow—only that there is a malfunction in one of them. This characteristic of electronic systems sets the limits on the boundaries of the blocks, and determines the point at which system logic can no longer be used. That is, the blocks are defined so that the parts that can not be individually identified through signal flow information are within the block. (This boundary situation occurs with physical subdivisions generally much smaller than chassis.)

It may appear that block boundaries cannot be rigidly defined because, with greater knowledge of electronics, more can be deduced about the specific location of a malfunction from signal-flow information. However, even with perfect electronics knowledge, a point will be reached at which a signal reading will be ambiguous because it is produced by the interaction of a number of parts or chains of parts, each of which contributes to the signal. The FORECAST concept is that system experts follow certain procedures to determine the point at which signal-flow information becomes ambiguous. This point marks the limit of the trouble shooting block. These blocks contain the fewest possible parts, so as to keep signal-flow logic applicable as long as possible. Within

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the block, another type of measurement will be used to investigate each of the converging chains independently.

Within-Block Trouble Shooting

It has been pointed out that, with the FORECAST approach, signal-flow information is abandoned at the point where a reading will be subject to more than one interpretation—always at the edge of a trouble shooting block. However, the FORECAST approach also provides a procedure for selecting and organizing a different type of measurement so that the same type of logic that supports signal-flow analysis can be applied within the trouble shooting block. That is, the logic is the same but the elements the logic refers to are changed. Signal-flow data have been the elements of the logic in the case just considered. Resistance and/or voltage measurements made at the ends of the converging chains are the elements of the logic within blocks. These within-block measurements are made just before the chains reach a common point of convergence. This is possible because of the characteristic of electron tubes that electronically isolates voltages converging on it while allowing the effects of these voltages to be felt as a common (signal-flow) output.

Either voltage or resistance measurements can be used in place of signal-flow measurements for trouble shooting within a block. If readings are taken at the tube pins—the points at which the parts or chains of parts typically converge and are attached—a bad reading will indicate that the parts in the chain attached there should be checked individually. After this finding, measurement of each part individually will identify the particular malfunctioning part within the chain. This part can then be replaced to repair the system.

There are certain situations in which all readings at the pins will be correct values. Under this condition the block is checked for "hidden parts," that is, parts whose malfunction would not produce an incorrect resistance or voltage reading at the tube pin but would nevertheless affect the signal at the block check point. To identify the particular hidden part which is causing the malfunction requires a knowledge of the nature of circuits that cause certain parts to "hide" or fail to produce a change in resistance (or voltage) readings at the tube pin to which they are attached. In the FORECAST procedures, each type of circuit that contains a hidden part is identified and described. These circuits are relatively simple—for instance, a resistor in series with a capacitor, or a high-resistance resistor in parallel with a low-resistance coil. Once such circuits are defined, students readily learn to recognize them. This knowledge is similar to that learned in basic electronics but is taught in the context in which it will be used.

A final feature of trouble shooting within blocks involves a short cut for identifying a part which is in a circuit attached to more than one tube pin. In this situation, the pin readings at both pins will be out of tolerance (assuming that this is not a hidden part). When this situation occurs, examining the schematic diagram will often lead to the identification of the common part without measuring each part individually.

This process often requires a few computations of the type made in using Kirchhoff's law.[1] Therefore, for this short cut, a type of knowledge found in current basic electronics courses must be learned by the trainee operating within the FORECAST approach to trouble shooting.

Implementation of the Approach

Under the FORECAST system-analysis approach, system experts following certain guidelines are able to bring to the trouble shooting process all the experience necessary to determine whether any given part will affect a measurement at a given point. They are able to devote unlimited time to making their determinations in advance of system malfunction. Their thorough analysis, covering every part of the equipment, will ensure that causes of even very infrequent malfunctions can be located.

These system experts determine analytically what parts can affect measurements at the selected check points. They verify their determinations on the equipment itself, and initial errors are corrected and rechecked. (The fact that these electronics experts make many initial errors in their determinations is evidence both of the difficulty of making the determinations and of the value of having experts make the determinations before the malfunction occurs.) They then mark existing schematic diagrams to indicate the limits of each group of parts or trouble shooting blocks in the system; they also stipulate the appropriate check points and the tolerances of measurements to be made at each point. This information is used to construct a trouble shooting block diagram.

Use of trouble shooting blocks as support material[2] in the field reduces the quantity of electronics data that the repairman must remember, while actually increasing the amount of electronics information available for use in the trouble shooting process. The result should be an increase in trouble shooting proficiency.

FORECAST Research[3]

One question studied in the FORECAST research was: Does the repairman <u>need to know</u> the correct values at every possible point in the system, or would knowledge of values at selected check points be sufficient? If every part in the system could be represented at one or another check point, and if measurements taken at these selected check points would yield information by which the repairman could isolate any part, then knowledge of correct values at the selected check points could

[1]In electronics, the law that: (a) In any branching network of wires the algebraic sum of the currents in all the wires that meet in any point is zero. (b) The total electromotive force around a circuit in which one or more electromotive forces are acting is equal to the sum of the resistances of its separate parts multiplied each by the strength of the current that flows through it. (After G.R. Kirchhoff, German physicist.)

[2]Samples of FORECAST support materials are presented in Appendix B.

[3]A report of FORECAST research may be found in HumRRO Technical Report 63, *Determining Training Requirements for Electronic System Maintenance: Development and Test of a New Method of Skill and Knowledge Analysis*, by Edgar L. Shriver, June 1960 (Task FORECAST I).

be considered sufficient. The sufficiency of the check points which emerged from the organization of the M-33 radar system into trouble shooting blocks was tested and verified by the electronics experts as a final step in the analysis of the system.

A second question investigated in Task FORECAST was: Can men of average intelligence learn about this selected set of check points in a limited time? This question was answered by training a group of students in this subset of knowledges. This procedure produced the answer that the knowledges could be learned well enough in 12 weeks to enable experimental students to perform as well as students trained in 30 weeks to learn all possible points. However, even though the experimental students did perform as well as the other students, it was clear that many experimental students had not learned the information as well as had the experimental students who performed best. Since this was the case, it is reasonable to assume that longer training periods will lead to an increase in proficiency of the slower students. That is, with an increase in training time to the duration now provided (about 30 weeks), marked improvements can be expected.

Section 2

DETAILS OF FORECAST METHOD: SYSTEM BLOCKING

PURPOSE OF ANALYSIS

The FORECAST maintenance method of electronic system analysis basically involves arranging the individual parts of the system into groups of parts termed "trouble shooting blocks."[1] Check points are found for the blocks, and the normal readings on test equipment at these points are accurately defined. The boundary for each block is drawn on a schematic diagram of the system so as to enclose all parts which affect the check point indication for that block. For this purpose, FORECAST researchers have used the type of schematic diagram currently employed in Army Technical Manuals to describe the system. The schematic diagram, as well as the trouble shooting blocks, preferably should be made up by the system analyzer specifically for the maintenance job. When all the blocks have been determined for a given system, the next step is to organize them into a trouble shooting block diagram, with each block showing simply the name of the functional stage or stages included in that block.[2]

To understand the details of this method, it is necessary to have a clear comprehension of what the analysis is designed to accomplish. In general terms, the analysis is designed to organize all electronic parts of a system in such a way that symptom and check point information can be more easily and more accurately interpreted by the maintenance man. The basic goal of the analysis is to organize the system from the standpoint of a trouble shooter, so as to increase his efficiency by increasing the speed and reliability of the decisions and interpretations he must make in locating faulty parts.

To accomplish this goal, the parts are examined with respect to (1) how they will affect the system when they malfunction, (2) where the effects of these malfunctions will appear on the equipment, and (3) what these effects will look like at selected check points and on external indicators. As a result of this analysis, the system is organized into a number of trouble shooting blocks, each containing a small number of parts. Associated with each block are one or more check points, each so selected that, if the reading is incorrect at that point and the block inputs are correct, then the block associated with that check point is known to

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[1]See general description of electronic weapon systems in Appendix A.
[2]For a sample block diagram, see Figure B-1, in Appendix B.

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contain one or more out-of-tolerance parts.[1] Groups of blocks in the same functional signal channel are associated with external-indicator symptom information which can then be used to indicate that a block within that channel contains a malfunction.

A number of points should be remembered with respect to the above description. In the first place, the organization is made in terms of trouble shooting. It is not based directly on the way the system functions, or the way it is physically packaged—for example, into chassis and cabinets—although these factors do somewhat affect the final form of the analysis. Rather, the organization is made to facilitate locating a malfunction. Such an organization obviously serves a very practical purpose and therefore, as will be pointed out further along, the analysis must consider many practical things, such as the type of test equipment available to the trouble shooter and the accessibility of check points.

Next, the purpose of the analysis is to increase the proficiency and efficiency of maintenance personnel. Thus, the analysis not only entails grouping parts so that they can easily be checked, but also involves determining the symptoms and check point indications that will tell whether certain groups of parts are functioning properly. In addition, all the materials, training techniques, and skills and knowledges which comprise the FORECAST training program are directed toward helping the repairman to use the organized results of the analysis most effectively.

Finally, the maintenance analysis is directly concerned with the problems the repairman encounters while attempting to select and interpret symptoms and check point information. It is generally agreed that these skills are the most difficult for the repairman to acquire. For example, some of the things which a repairman must now do while locating a malfunction are:

(1) Interpret symptom information in terms of the area of the system in which the malfunction(s) is located.

(2) Select check points at which reliable information can be obtained regarding the "goodness" of the parts associated with that point.

(3) Determine what parts are being checked at a particular check point.

(4) Determine what the correct reading should be at a particular check point.

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[1]At any particular check point, the selection of the type of measurement to make—voltage, wave form, frequency, or some other—is based on considerations of the circuit make-up and the critical aspects of the check point reading. For most circuits there is one type of measurement which is most appropriate, but even this is often no more than 95 per cent reliable. This reliability problem is currently being studied by the National Bureau of Standards Fault Location Measurement Techniques (NBS Project 0106-20-01416). To date their studies indicate that typical electronic stages can be checked with some type of single measurement with a reliability of 90 to 95 per cent. Thus, for a complete checkout of the circuitry, two or more types of measurements are usually needed.

With the FORECAST method, the above decisions and interpretations are made by skilled analysts; in a sense, the system is "pre-trouble-shot." By organizing the system into trouble shooting blocks, the relation of check points to specific blocks is predetermined, as are the correct readings that should appear at these points. In addition, groups of blocks are associated with symptom information so that the repairman can easily learn to interpret this information in terms of which blocks might contain the trouble. Finally, during conferences and practical exercises, the repairman can be taught the most efficient selection of check points for isolating malfunctions within each area of the system.

The reader is probably aware that organizing a system into blocks for the purpose of increasing trouble shooting proficiency, as well as for understanding system functioning, is not exactly a new procedure. With respect to chassis, such an organization now exists. That is, each chassis in a system usually produces only a few outputs that, when found to be correct, indicate that the chassis is functioning properly. This organization of parts into a chassis, along with the use of chassis-output information to evaluate the condition of the chassis, forms the basis for current training in system trouble shooting.

At present, there is no attempt to employ this type of organization or the principles of system trouble shooting to parts within a chassis. The FORECAST staff found that this could be done. In actuality, a chassis often consists of a series of functional stages which could, with a proper basis for subdivision, be packaged as subchassis or modules. In the form of block-diagrams, Task FORECAST researchers have performed this type of packaging, on paper, and have found it to be of great aid to the trouble shooter. In effect, the FORECAST analysis results in the arrangement of an electronic system into modular form for trouble shooting. The remaining aspects of the analysis involve the determination of what information and materials are needed to support and use this organization most efficiently.

DEFINITIONAL PROBLEMS

What Is a Trouble Shooting Block?

The nature of a trouble shooting block has been described in general terms. The following sections describe more fully the characteristics and uses of such blocks.

A trouble shooting block consists of a fairly small group of parts which has one or more well-defined inputs and outputs. The relation of the block to its parts is such that, when all block inputs are good and one or more block outputs are bad, the malfunction(s) must, in all probability,[1] be produced by one or more of the parts located within the block.

Trouble shooting blocks are conceptually similar to "functional stages" in an electronic system but are different in that the relation of the block parts to the block outputs has been rigorously defined. In addition, a trouble shooting block may sometimes contain more than one stage.

[1] See footnote on page 13.

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These blocks are used in two ways. They are used as conceptual devices for promoting a thorough understanding of a system which they comprise. In this respect they are similar to stage block diagrams. They are also used, by themselves, as trouble shooting aids, and are designed to provide the maintenance man with a reliable means of rapidly trouble shooting to a small area of the equipment. Blocks used for trouble shooting can be designed on the basis of where they are to be used—on site or in the maintenance shop.

Why Should Block Inputs and Outputs Be Well Defined?

To isolate a malfunction to one block, that block with good input(s) but with bad output(s) must be found. To do this the repairman must be able to discriminate accurately between "good" and "bad" signals.

There are many factors which affect signal discriminability. Among them are the sensitivity of the testing instrument, the degree to which the critical features of a "good" signal are distinctively different from those of a "bad" signal, and the degree to which the measurement is masked by other signals at the same measurement point.

Discriminating between a good and a bad signal can involve such things as detecting small changes in signal amplitude or signal rise-time. Changes such as these are relatively difficult to distinguish. Thus, the critical features of the signal have to be defined accurately, and the repairman's attention directed toward them. One way of handling this discrimination problem is to attempt to design blocks and select check points so that the measured signals are maximally discriminable in terms of "good" or "bad" ("go" or "no go").

A special problem is presented when the output of a block is masked by signals from other blocks. This can occur when the outputs of two blocks each feed into a third block at the same point. Usually this point is the best place to measure the output of both blocks. However, to obtain measurements that are readily discriminable, something must be done to the system to remove the unwanted signals. Many times, pulling a tube in the block whose output you do not want to measure will unmask the signal of the other block. In other instances, the system may have to be placed in a certain mode of operation to eliminate the unwanted signal at the common check point. Such practical procedures for obtaining good signal measurements will be discussed at length in this manual.

Why Should the Relation Between a Block and Its Parts Be Well Defined?

The basic trouble shooting procedure is the successive elimination, by interpretation of measurement information, of those parts of the system that are not causing the trouble. Eventually the trouble shooter is left with one or more out-of-tolerance parts which are repaired by adjustment or replacement. For this procedure, the repairman must be able to accurately interpret check point information in terms of what parts produce the signal at any given point. Such interpretations can involve much time-consuming thought, and, unless the repairman is

unusually knowledgeable in electronics, he may easily make errors of interpretation. With well-defined blocks, the time spent in interpreting check point information can be markedly reduced and the accuracy of the interpretations greatly increased.

With the blocks predefined, the repairman does not have to determine for himself what parts he has checked at a particular point. This will have been done already by expert electronic system analysts who have indicated their determinations by enclosing the parts within blocks on the schematic diagrams. Then, when the repairman, by signal checks, locates the block that contains the malfunction, he can go to the schematic diagram of that block and readily determine what parts comprise it. Within-block trouble shooting procedures can then be employed to trouble shoot the small group of parts within that block.

Why Are Blocks Designed Differently Depending on the Locale of Trouble Shooting?

The use of blocks in trouble shooting entails checking block inputs and outputs, and interpreting these measurements. Various pieces of test equipment, sensitive enough to adequately check out the block, are required. In addition, the check points must be accessible. Test equipment availability and check point accessibility will differ, depending on whether the trouble shooting is being performed on site or at the maintenance shop.

On-site trouble shooting involves the use of common portable test equipment; at the maintenance shop, permanently installed and, in general, more sensitive and more accurate test equipment is available. In addition, on-site trouble shooting is usually performed with the chassis in the system and with the normal operating inputs applied to the chassis. When the chassis is mounted in the system, there are some check points which may not be accessible because of their physical position. At the maintenance shop, special equipment is used to apply chassis inputs, and the chassis can be placed so that almost all possible check points are accessible. Finally, it may be that the special input signals required to completely check and adjust the chassis are not readily available on site; they usually are available at the maintenance shop. Thus, blocks can be designed differently, depending upon the availability of test equipment and chassis inputs, and the accessibility of check points. The blocks we will discuss were designed for on-site trouble shooting.

KNOWLEDGE REQUIRED OF A SYSTEM ANALYST

A system analyst should be highly knowledgeable in electronics and should be particularly familiar with the type of electronic system he is about to analyze. Specifically, he must be able to examine schematic diagrams and determine what parts affect measurements at various check points. He should be thoroughly familiar with the practical aspects of trouble shooting, as it is these practical aspects which determine the final configuration of the trouble shooting blocks.

Obviously, at some point the analyst should gain a thorough understanding of the system he is analyzing. This information is difficult to obtain before the analysis begins, but the FORECAST staff has found the following general procedure adequate for acquiring the necessary information for system analysis.

The over-all function of the system, including its theory and operation, is reviewed and clarified. A channel of the system is selected and analyzed into blocks; then a second channel is selected and blocked. In most cases blocking will not proceed very far without additional information. The manufacturers' preproduction publications and like sources are examined, and the information gleaned is applied to the analysis. In practice, the system is organized into blocks until further progress is not possible. The technical handbooks or the system itself is then consulted for more information. By this process, tentative blocks are created, then revised on the basis of additional information, and then checked for accuracy. This blocking by successive approximation eventually produces both final authentication of the trouble shooting block diagram for the system and a thorough understanding of the system by the analysts.

ANALYSIS OF R/C COUPLED AMPLIFIERS

The Relation of Parts to Block Outputs

Figure 1 contains a schematic diagram of an R/C coupled amplifier (less heater circuitry), plus a few parts in the next stage of the signal chain. This schematic diagram can be used to demonstrate many of the principles of dividing the system into trouble shooting blocks. The analysis of Block A of Figure 1 is considered first, and is then reviewed for the purpose of interpreting some of the principles and assumptions used in establishing the trouble shooting blocks.

Tube V1 and its associated parts form a stage of amplification whose output is coupled through capacitor C4, developed across resistor R6, and applied to the control grid of V2. This V1 stage has only one signal output that is applied to V2 at its grid. Thus, the output check point for Block A can be selected at the grid of V2. The signal at this point is not DC; therefore, it can be assumed that an oscilloscope will be the measuring instrument used at this check point. The question now is, what parts affect the reading at this point?

"Common" Part. First consider C4. Assuming that C4 is open, what will that do to the signal at V2? It will block its passage from V1, the reading at the grid of V2 will be incorrect, and therefore C4 appears to belong in Block A. Remember that any part that affects the output of a block must be located within that block.

Now assume that C4 shorts. When this occurs, the AC signal will be passed and will appear at V2. It appears, then, that a shorted C4 will not affect the AC signal output of Block A. However, it is known that when C4 shorts, the plate voltage of V1 will be applied to the grid of V2. This will cause a bad output to appear at the output check point for Block B. (Remember, it is assumed that an oscilloscope is used to check Block A.) The oscilloscope will not detect the presence of DC

Blocked R/C Coupled Amplifier, Showing Treatment of Common Parts, Parts in B+ Supply, and Between-Chassis Blocking
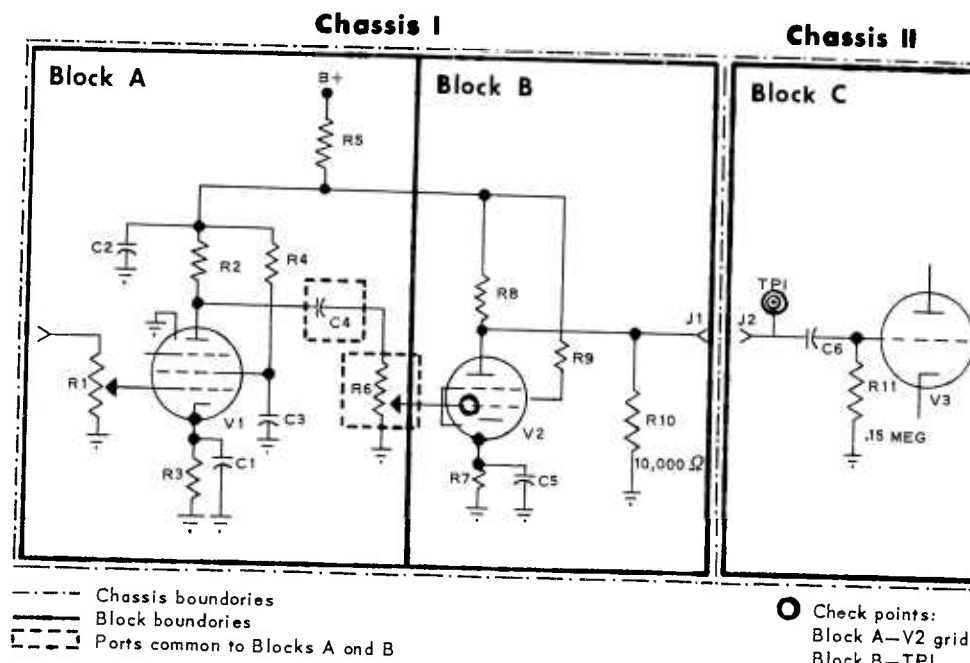
Figure 1

voltage—only of AC voltage. Therefore, if C4 is shorted, the reading at the grid of V2 will appear to be correct; that is, a shorted C4 will not seem to affect the output signal. It appears, then, that there are reasons for associating C4 with both Block A and Block B. This can be done by labeling C4 a "common part," as it can affect the output either of Blocks A and B, or of Block B alone, depending on how it malfunctions.

The placement of grid resistor R6 into Block A requires some comment. The control grid of V2 has been designated as the output check point for Block A. This means that R6 should affect the output of Block A as measured at the check point. Clearly, if R6 shorts, the output will be bad. What if R6 opens? In this case, also, the output of Block A will be bad. This is because R6 normally has a value low enough to load the previous circuitry. Therefore, when it opens, it unloads the circuitry and will produce a bad signal at the grid of V2. It is important to note that R6 is a variable resistor. Therefore, the value of this resistor can be so high that it does not heavily load the previous circuitry. Under this condition, when the grid resistor opens, it is doubtful whether the effect on the signal appearing at the grid of V2 would be noticeable. If the resistor shorted, it would still affect the output. Thus, R6 should be labeled "common" because it would affect the check point reading of either Block A or Block B depending upon its adjusted value.

The Effect of "Shorted" Parts. When capacitors short, DC voltage is usually applied to some parts that do not normally have this voltage applied to them. When analyzing the possible effects of this occurrence,

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the effects of the increased current that flows through these parts due to the short must be considered. The question usually asked is whether the wattage of the parts is high enough to withstand the additional current.

In Figure 1, when C4 shorts, the current flowing through R6 will increase and this could cause R6 to burn out. If so, the result would be a bad signal appearing at the grid of V2. If R6 is a high-wattage resistor, this probably would not happen and the AC signal at the grid of V2 would appear correct. It is then seen that the assignment of C4 depends on whether a shorted C4 would cause R6 to burn out. If it would, C4 would be assigned to Block A because the output for Block A would be incorrect regardless of how C4 malfunctioned; if R6 would not burn out, then C4 would be labeled a common part.

Whether R6 does or does not open as a result of C4 shorting, the plate voltage of V1 will be applied to the control grid of V2. This relatively high positive voltage will cause V2 to conduct heavily and to draw grid current. Thus, damage can result to the tube itself, the plate load resistors R8, R2, and R5, and/or the grid biasing resistor R7, depending on their relative abilities to withstand current overload. A first approximation as to which of these items will fail can be obtained by calculating the dissipated power per part when the plate voltage from V1 is applied to the control grid of V2. The published characteristics for V2 would be used to make this determination. A simpler technique is to assume that the entire B+ voltage is dropped across the voltage divider consisting of R5, R8, and R7. By computing the voltage distribution, it is possible to estimate whether the ratings are being exceeded. If they are, then one or more of the resistors will fail. If it is concluded that these parts will fail, then they must be placed in Block A. If they appear to be able to stand the load, they can be placed in Block B. Fortunately, it appears that most resistors have high enough ratings so that they can withstand the increased current that may result from a shorted capacitor. It should be noted, however, that even if R5, R7, and R8 can withstand the load, tube V2 will ultimately fail.

Parts That Directly Affect Two or More Blocks. In Figure 1, resistor R5 is located within Block A. Although this part directly affects two blocks, it is not labeled a common part, for the following reason: According to the FORECAST trouble shooting rules, the repairman system trouble shoots until a block is found with good signal inputs and one or more bad signal outputs. If R5 were to open or short, the output of both Block A and Block B would be directly affected. The repairman, however, should deduce that the trouble lies in Block A because this block has a good signal input. Resistor R5 should therefore be assigned to Block A.

Check Point Accessibility vs. Size of Block

In the introduction to this section if was stated that the size of blocks should be kept to a minimum. This reduces the number of parts that must be checked by more time-consuming chassis trouble shooting procedures. Also, block size varies widely because of other blocking and practical trouble shooting considerations. Suppose, for example, that

Chassis I in Figure 1 were encased so that the tube pins were not accessible, and the chassis so arranged in the system that tube adapters could not be used. Obviously, the output of Block A would not be accessible. Thus, Blocks A and B would have to be combined into one block.

A more typical case is where tube pins are accessible through the use of tube adapters. In these instances blocking can be arranged as in Figure 1.

Review of Some Principles of Blocking

The above discussion contains many points that need to be explained in more detail.

(1) <u>Blocking involves the determination of what parts affect the reading at a particular point</u>. The analysis began with a general description of the signal flow through a stage, then quickly arrived at a point where the output of that stage might be measured. First, a tentative check point must be selected; notice, also, that the check point at a tube pin was selected. This was done because check points must be accessible. To meet this requirement, it is best to select built-in check points, at the ends of cables or at tube pins.

(2) <u>Assumptions regarding test equipment play an important role in the FORECAST type of blocking</u>. In general, a measurement is made with an oscilloscope or a voltmeter. The use of either one of these instruments places restrictions on the measurements that can be made at a given point. Usually, an oscilloscope will be used to measure signal flow. This device does not detect DC voltage; therefore, the analysis must be made in terms of whether defective parts will affect AC or DC readings. The use of an oscilloscope means that most coupling capacitors will be designated as common parts because these parts, if shorted, will not affect the AC reading at one check point but will cause a bad AC reading to appear at the check point for the next block.

(3) <u>Dealing with shorted parts can be particularly troublesome because a determination must be made regarding the effect of increased current on other parts in the circuit</u>. If these parts can not withstand the increased current, then they must be placed in the block containing the part that originally shorted. Fortunately, design engineers seem to have anticipated this problem, as many resistors have wattage ratings high enough to withstand loads due to shorted capacitors.

(4) <u>The general principle regarding the treatment of common parts is fairly clear-cut</u>. When a part affects the output either of Blocks A and B, or of Block B, depending on how it malfunctions, it is called a "common part." On the other hand, if a part directly affects the output of more than one block, regardless of how if malfunctions, it is assigned to the first block in the signal chain which it affects.

Treatment of Power Input

Throughout this section, signal inputs and outputs will be discussed, but it is also known that chassis can have power inputs. How do we determine that these inputs are good? That determination is not directly

accomplished through blocking considerations. For example, in Figure 1 the parts were analyzed in terms of their effect on signal flow. Resistor R5, which is part of the power input, can affect the signal output of Block A. Therefore, if the signal input to Block A is good but the output is bad, then we must consider the possibility that R5 is bad. In addition, we should check the power input to Block A before checking the individual parts. This can be done either by built-in meters or by checking the B+ input to Block A. The important point to remember is that the system is analyzed primarily in terms of signal flow, and, when trouble shooting, the repairman first reduces the trouble to a block whose signal inputs are good but whose signal outputs are bad. The next trouble shooting step, before removing the chassis from the system, is to check the power inputs to that block.

The Determination of "Best" Solutions

By now the reader is probably aware that few simple and clear-cut rules can be written regarding the FORECAST techniques of blocking. At certain points, the analyst, using the general blocking guidelines, must also use his own best judgment, the goal being to organize parts of the system so that interpretations regarding their functioning can be made with a high degree of reliability. The following discussion of the R/C coupled amplifier demonstrates one procedure for arriving at a "best" solution.

Figures 2 and 3 are schematic diagrams of a hypothetical R/C coupled amplifier. The amplifier has been divided into trouble shooting blocks in two different ways. The reasoning which went into blocking Figure 2 will be discussed first.

The check point for Block A has been located at point G, the accessible grid terminal of V2. Now we must decide where to make the "cut" between blocks. As shown, the block boundaries cut the chassis into two blocks, placing both C and R in Block A. The problem is, should these two parts be unequivocally located in Block A? To consider this problem, assume that certain types of malfunctions occur in parts C and R, and determine the effect of these troubles as viewed at check point G. Let us assume that R normally does not load V1.

Assume first that R shorts. Clearly, if R is shorted, then the signal at check point G would be incorrect. Since G has been designated as the check point for Block A, a bad signal here means that we should expect the faulty part to be either in Block A or in some block before Block A, but not in Block B or a succeeding block. We know that the bad part is R, and it is indeed in Block A. Hence, R correctly belongs in Block A as regards its effect on the measurement at G when R has shorted.

Now assume that R opens. Since we have assumed that R does not load V1, the measurement at G would appear correct. Therefore, we have a good check point reading for a block that contains a faulty part. This indicates that part R does not belong exclusively in Block A, because it produces different effects depending on how it fails. Therefore, it should be designated a common part.

R/C Coupled Amplifier Blocked So That "Common" Parts Exist
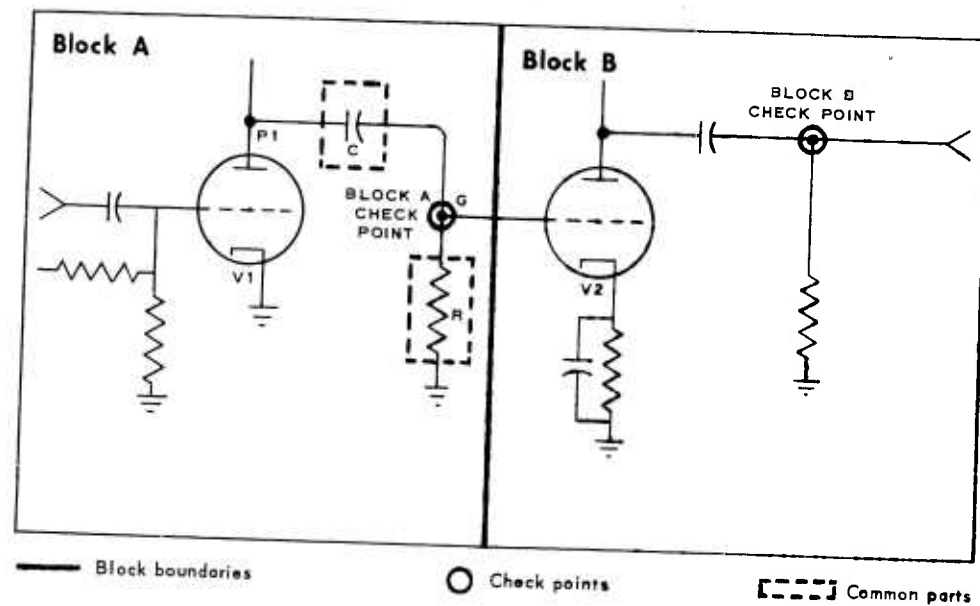
Figure 2

R/C Coupled Amplifier Blocked to Eliminate One Common Part
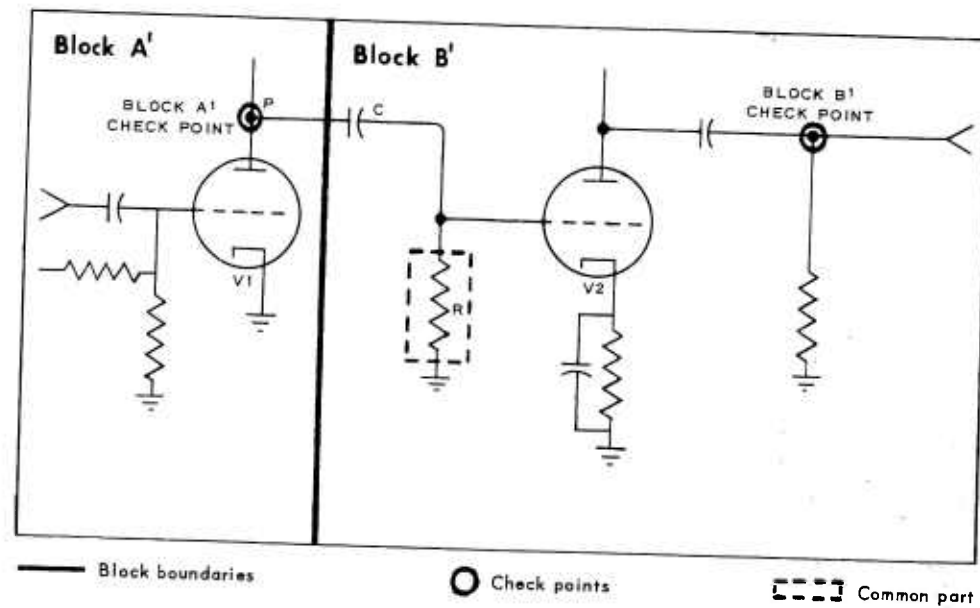
Figure 3

Now apply the above procedures of analysis to capacitor C in Figure 2. Assume first that the capacitor shorts. When C shorts, the signal appearing at point G should remain unaffected, because the signal is AC in nature and the AC continues to appear properly at G. Of course, the DC plate voltage is coupled to the grid of V2. However, if the measuring instrument is an oscilloscope that is not DC-coupled, and if the instrument can stand the value of the plate voltage, then the signal will be observed as correct at the grid of V2. In this instance we have a good check point signal for a block that contains a faulty part. On the other hand, if the capacitor opens, the check point signal will appear as incorrect. Again, we have the conditions which necessitate classifying a part as common to more than one block.

Based on the above considerations we can conclude that, with blocking as shown in Figure 2, both R and C are common parts. This conclusion may be modified by probability considerations. That is, we may consider the blocking solution with respect to the likelihood that resistor R will short, as compared with how likely R is to open. If we conclude that R is most likely to open and that shorting will be a rare occurrence, then, in the event that R does not load V1, we can place R with V2 in Block B. This assumes that, when R opens, it will affect the output of V2, even if it won't affect the V1 output. If we assume that R does in fact load V1, then we may without hesitation place it in Block A, as, regardless of how it fails, it will affect the signal at point G.

Consider now the R/C amplifier blocked as shown in Figure 3. Here the output check point for Block A' is located at point P, and parts C and R are located in Block B'. Assume that R does not load V1. Again, the problem is to determine what effect shorting and opening the parts will have on the signal appearing at check point P.

In Figure 3, if R shorts, then the measurement made at P will be incorrect because point P will be grounded AC'wise through part C. If R opens, its effect would not be noticed at check point P. This means that part R should be called a common part. Now assume that part C shorts. This has no effect on the signal reading appearing at point P. If C opens, and R does not load V1, then the signal at point P will appear correct. Thus, part C appears to be properly located in Block B.

By making use of probability information regarding the way parts usually malfunction we reach the conclusion that R should be placed in Block B, since it is unlikely that R will short, and it is only when R shorts that it would affect the signal at point P. With these probability considerations, there need be no common parts in the blocking of Figure 3. On the other hand, if we find that R loads V1, then, if R fails by opening, it will affect the measurement at P, and therefore should be a common part. For the same reason, when C opens, the effect will be seen at point P.

Figure 4 is a tabulation of the results developed above. The three blocks are shaded to call attention to the fact that those particular conditions determine that the part must be labeled common. As can be seen, there is no exact solution to this blocking problem. The best solution seems to be to make C common all the time and perhaps R also, unless the details of the specific circuits can permit the unequivocal assignment

How Malfunctions of Parts Affect Measurements at Check Points

	Part	Check Point Measurement	
		Shorted	Open
Figure 2 Block A Check Point at G	R	Bad Reading	Good Reading
	C	Good Reading	Bad Reading
Figure 3 Block A[1] Check Point at P	R	Bad Reading	Good Reading
	C	Good Reading	Good Reading

Conditions under which blocking logic would be violated unless ports were made common to both blocks

Figure 4

of a part to one or another block. It is evident that there is an ambiguous boundary between the blocks in Figures 2 and 3. The specific circuitry helps to clarify the ambiguity, but there is no ironclad rule for assigning the parts that comprise the boundary.

Instead of labeling C common all the time, DC levels can be measured as well as AC signals. If the test oscilloscope were set up to measure DC, then the plate voltage appearing at the grid of a tube as the result of a shorted coupling capacitor would cause the signal at the tube grid to be displaced by a large DC level. This trouble shooting procedure would require the repairman to set his scope attenuation properly, so as to account for the possibility of measuring plate voltages at the tube grid. If plate voltage existed at this point, it might be so large in comparison to the AC signal that the signal would be unobservable when the DC trace was shown.

Treatment of Coupling Networks Between Chassis

So far, only blocks whose parts were all located within one chassis have been considered. The analysis of networks which couple blocks located on different chassis must also be considered.

In Figure 1, Block B feeds into Block C, located on Chassis 2; the two chassis are connected by a cable. The signal from V2 is developed across the parallel combination of R10-R11 and applied to the grid of V3. This situation could be blocked in the same manner as coupling networks within chassis. When this is done it often happens that parts contained within one block are located on two different chassis. This is sometimes unavoidable from an engineering viewpoint. In general, blocks should be so defined that all parts are located on one chassis whenever possible.

In the analysis of Blocks B and C, let it be first assumed that Block B can be checked at the grid of V3. What parts belong in Block B? If C6 shorts, the signal will still appear correct at the V3 grid; if C6 opens, the signal at that point will be bad. Therefore, C6 is a common

━━━ Black boundary

⬤ Check paint

NOTE: All values expressed in ohms and microfarads unless otherwise indicated.

With Previous Chassis

26
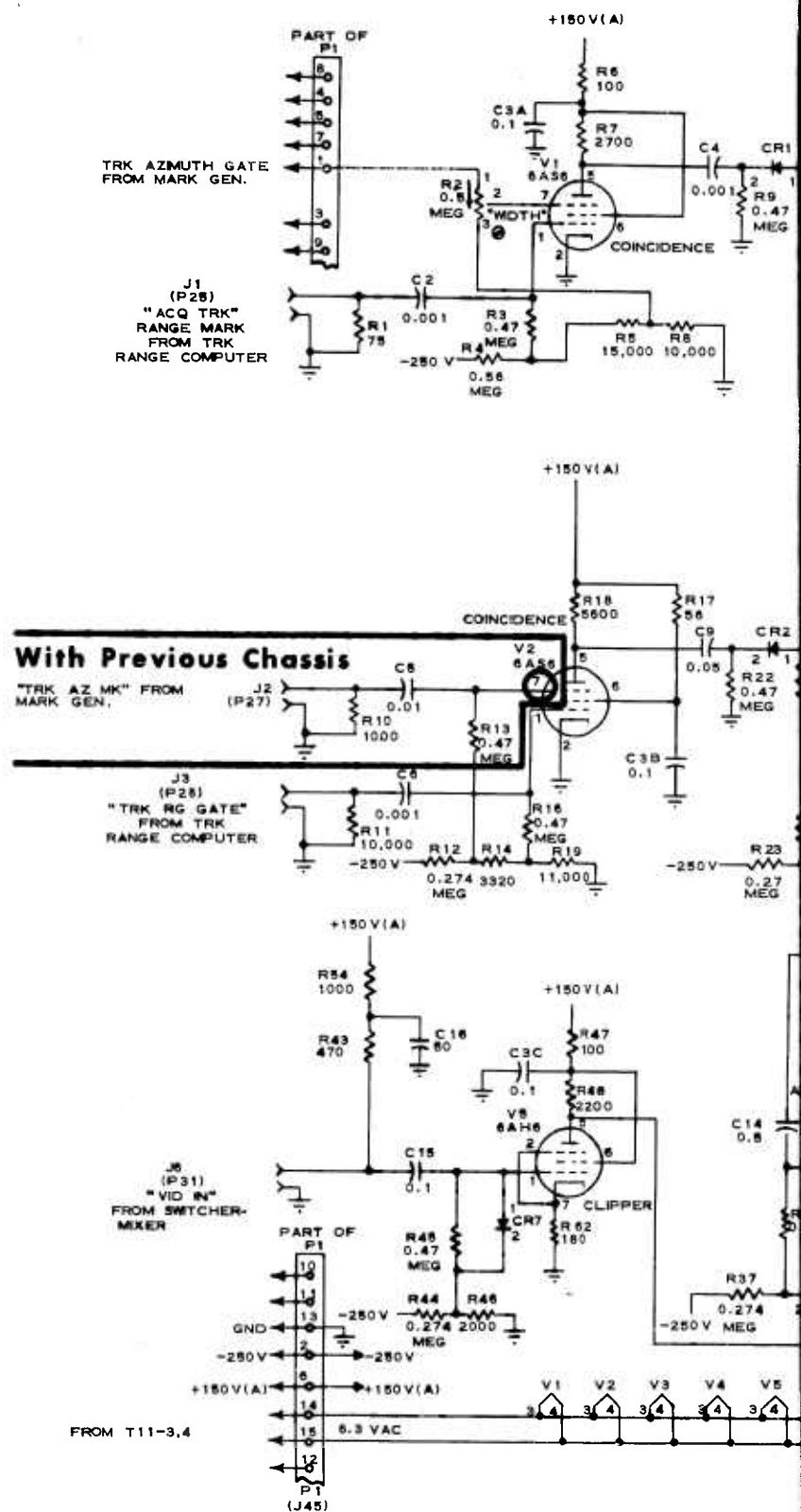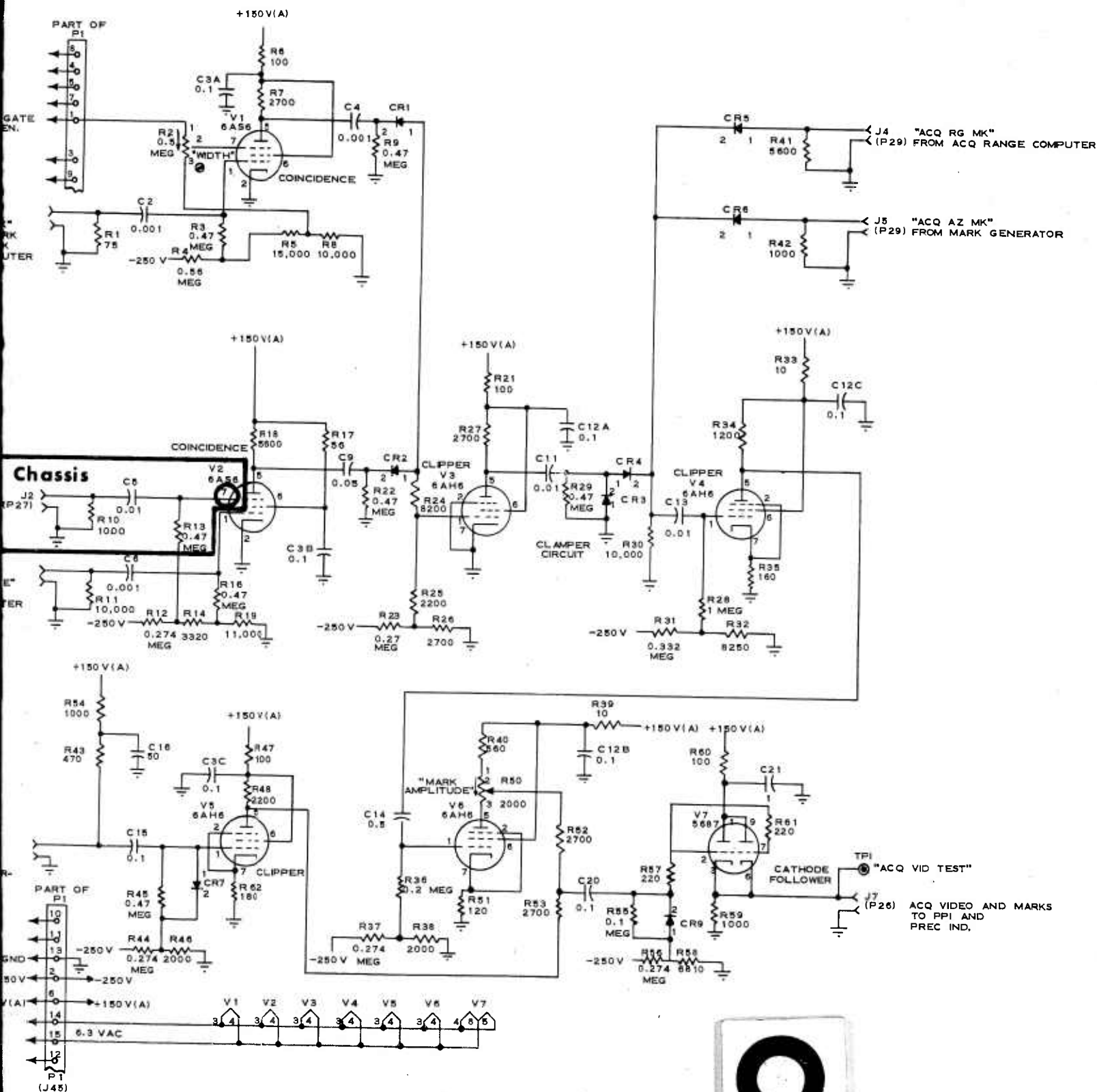
Figure 5

Figure 5

part with respect to a check point at the grid of V3, because it affects the output either of Blocks B and C, or of Block C only, depending on how it malfunctions. Assume that R11 will open if it malfunctions (a safe assumption with composition resistors); then R11 belongs in Block C. This is because it does not load the circuitry before Block C and because the oscilloscope probe and input circuitry will simulate R11 sufficiently so that the signal appearing across R10 can be seen through Capacitor C6. Thus, one solution would be to make the break between Blocks B and C at C6, and call C6 a common part.

An even better solution would be to make TP1 the check point for Block B. A check here would not be affected by malfunctions of C6 or R11, unless R11 shorted. Thus, C6 could be placed solely in Block C, and all parts associated with Block B would now be located on one chassis.

It should be noticed that a check point could be located at J1 instead of at TP1. As a general rule, it is preferred to select a check point on the far side of a cable—that is, on the receiving end of the cable. This assures that the cable, as well as the parts within the block, are checked out by measurements at the check point.

Figure 5 presents a typical problem regarding the treatment of chassis inputs. This example is taken from the M-33 Video-and-Mark Mixer chassis. Here the problem concerns the placement of R10. This resistor is a terminating resistor for a block located on a chassis before the one shown here. The output of this block could be checked at V2 pin 7. If this were done, all the parts attached to this pin would have to be analyzed with respect to their effect on the AC signal at pin 7. As a result, R10, plus additional parts, would be placed in a block located on the other chassis.

In practice, the repairman would have little difficulty handling this distribution of parts. For example, bad reading at V2 pin 7, but good inputs to the block being checked at this point, would lead to replacement of the chassis containing that block. If the trouble persisted, then the cable, R10, C5, or R13 on the Video-and-Mark Mixer chassis must be at fault.

There is an alternative point to check point V2 pin 7 that could be chosen and that would simplify the block analysis. A check could be made at J2 (P27). To make this check, the J2 cable would be disconnected from the Video-and-Mark Mixer chassis and an oscilloscope probe inserted into the end of the cable. This procedure removes the parts connected to V2 pin 7 from the circuit under test, and the signal appearing at J2 is now developed across the input impedance of the testing equipment. A measurement at J2 can be compared with the "normal" reading obtained with the same test equipment when the system was known to be functioning properly. If the measurement is incorrect, the fault must lie in the cable or in blocks before J2. All the parts connected to V2 can now be located on the same chassis and will affect only the output of V2.

The above example makes use of an important testing principle. That is, the reading at a check point is a function of the state of the system plus the effect of test equipment being connected into the system. The act of testing a signal may change some characteristic of the

signal. This is unimportant, so long as the obtained measurement can be used to evaluate the system accurately. Normal check point readings are obtained on a properly functioning system, with a specific piece of test equipment, and with the system and test equipment controls set in a particular manner. For greatest accuracy, subsequent measurements at these points must be taken under the same test conditions and with the same type of test equipment. If the repairman is not careful in this, the obtained measurements may not match the measurements taken under normal conditions.

As a final example of the treatment of chassis inputs, assume, as shown in Figure 6, that there is a test point, TP2, associated with the input at J2. The output of the previous block could be checked at TP2. However, the reading at this point would be affected by the condition of R10. Thus, this part would have to be assigned to a block located on the chassis before the Video-and-Mark Mixer.

EXAMPLE OF A COMPLETE SCHEMATIC ANALYSIS

Function Description

Figure 7 presents the schematic diagram of the M-33 Video-and-Mark Mixer chassis. This diagram will be completely analyzed to point out some additional blocking considerations.

A brief description of the function of the stages within this chassis is appropriate here. On the M-33 PPI there appear marks which represent the range and azimuth positions of both the tracking and the acquisition radar antenna. (See Figure 8.) The marks for the tracking radar appear as a cross, called the electronic cross. The arc portion of this cross represents the range setting of the tracking radar computer; the radial portion represents the present azimuth position of the tracking radar antenna. The range setting of the acquisition radar computer is represented on the PPI by the continuous circle whose distance out from the center of the PPI represents range. The azimuth representation for the acquisition radar is a radial mark that continuously extends from the center to the edge of the PPI. The signals that produce the above marks originate from various places in the system and are mixed in the Video-and-Mark Mixer. They are then combined with video return and all signals are sent to the PPI.

Blocks With a Common Check Point

The analysis begins with V1 (in Block A of Figure 7) continuously receiving range marks representing the range of the tracking system. It also receives an azimuth gate signal. These signals are combined in coincidence stage V1, and the output is a gated signal that eventually appears as the arc or range portion of the electronic cross. This signal is sent to the grid of V3; this point seems to be a good place to measure the output of V1. What parts will affect the reading at this point? For the moment, assume that CR2 and everything to its left is removed from the chassis.

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Block boundary

Check point

NOTE: All values expressed in ohms and microfarads unless otherwise indicated.
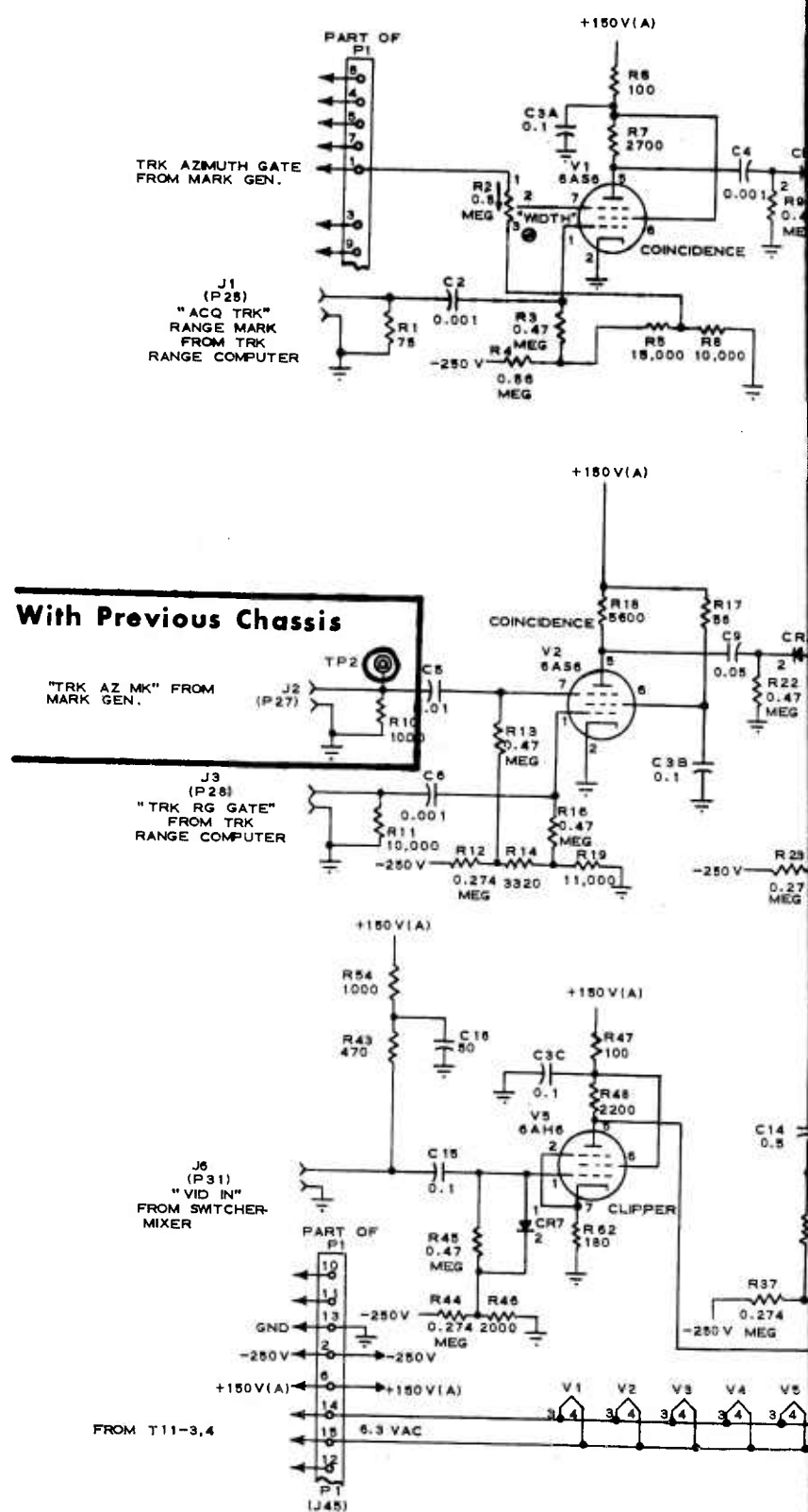
PART OF P1

+150V(A)

R8 100

C3A 0.1

R7 2700

C4 0.001

TRK AZIMUTH GATE FROM MARK GEN.

V1 6AS6

R2 0.5 MEG

"WIDTH"

COINCIDENCE

R9 0.1 MEG

J1 (P28) "ACQ TRK" RANGE MARK FROM TRK RANGE COMPUTER

C2 0.001

R1 75

R3 0.47 MEG

R4 0.56 MEG

−250 V

R5 15,000

R6 10,000

With Previous Chassis

+150V(A)

COINCIDENCE

R18 5600

R17 56

C9 0.05

CR

"TRK AZ MK" FROM MARK GEN.

TP2

J2 (P27)

C5 0.1

R10 1000

V2 6AS6

R13 0.47 MEG

R22 0.47 MEG

C3B 0.1

J3 (P28) "TRK RG GATE" FROM TRK RANGE COMPUTER

C6 0.001

R11 10,000

R16 0.47 MEG

−250 V

R12 0.274 MEG

R14 3320

R19 11,000

−250 V

R29 0.27 MEG

+150V(A)

R54 1000

R43 470

C16 50

+150V(A)

C3C 0.1

R47 100

R48 2200

V5 6AH6

C14 0.5

J6 (P31) "VID IN" FROM SWITCHER-MIXER

C15 0.1

CLIPPER

PART OF P1

R45 0.47 MEG

CR7

R62 180

GND

−250V

R44 0.274 MEG

R46 2000

−250 V

R37 0.274 MEG

−250V

−250V

+150V(A)

+150V(A)

FROM T11-3,4

6.3 VAC

V1 V2 V3 V4 V5

P1 (J45)

Figure 6

Figure 6

Block boundaries

O Check points:
Block A—V3 pin 1, pull V2
Block B—V3 pin 1, pull V1

Common parts:
R24, R25, and R26

NOTE: All values expressed in ohms
and microfarads unless
otherwise indicated.

30
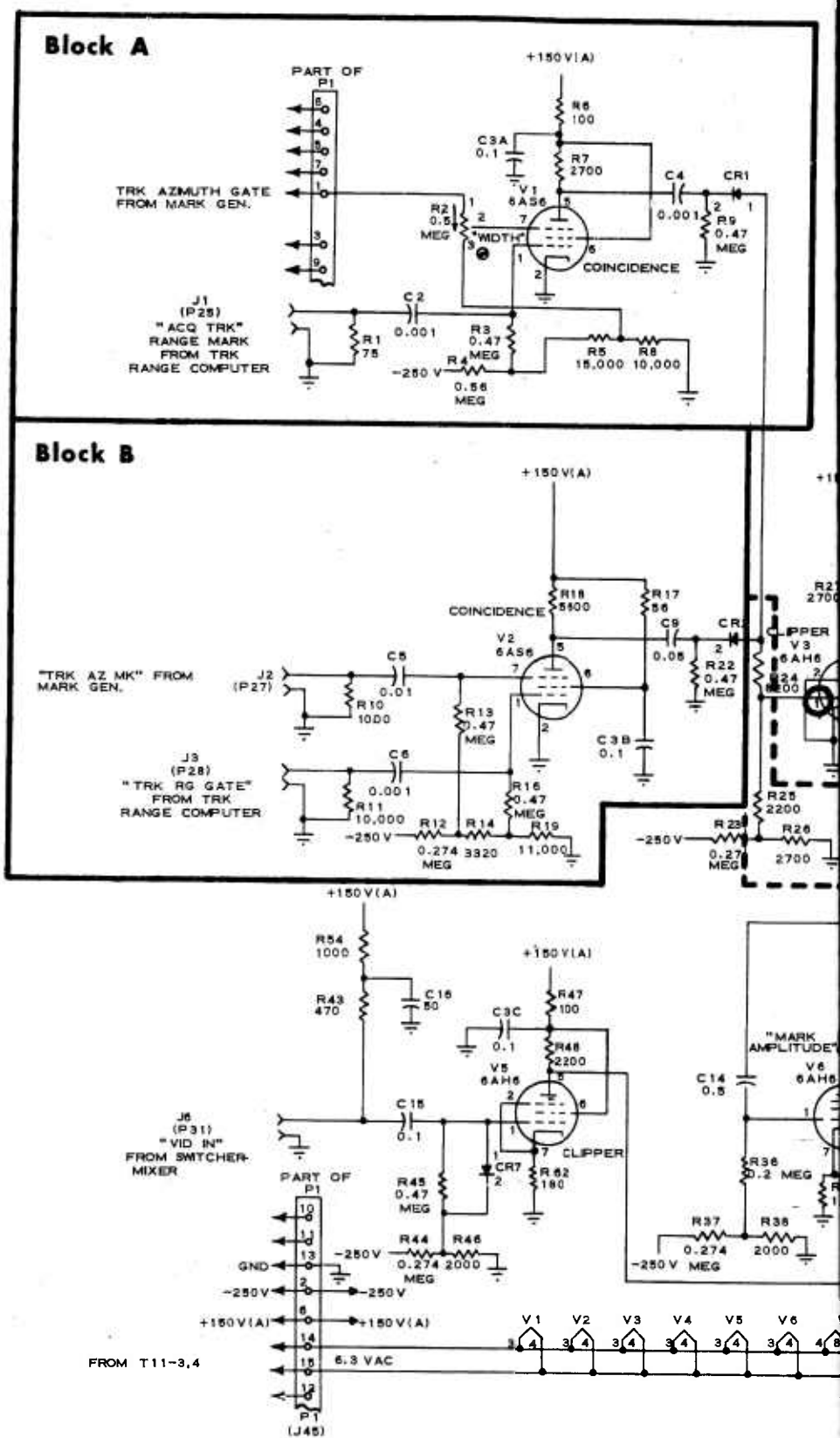
Figure 7

Figure 7

Plan-Position Indicator Presentation
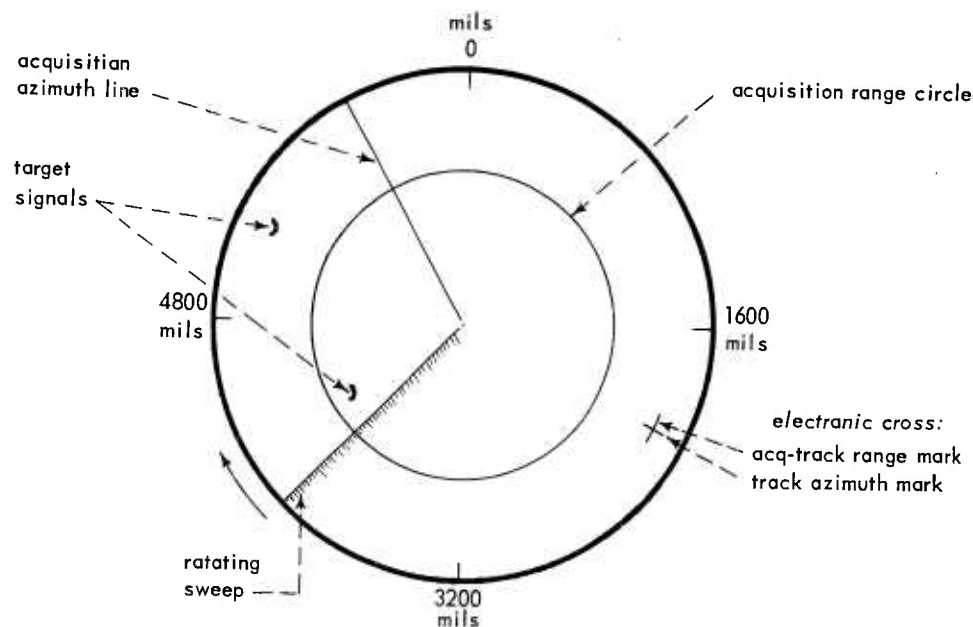
Figure 8

The output of V1 passes through C4 and CR1, and then is developed across R24, R25, and the parallel combination of R23 and R26. Since R23 is much greater in value than R26, its effects on the AC output of V1 can be ignored. However, R24, R25, and R26 do affect the output of V1 and, therefore, should be placed in the V1 block. On the other hand, if R23 goes bad, the bias at V3 will be incorrect and thus this part should be put in a block with V3.

Now V2 (in Block B) must be considered. This coincidence stage receives two signals: One signal, the Track Range Gate, appears at the control grid of V2 once per sweep; the other signal, the Track Azimuth Mark, appears only when the azimuths of the track and acquisition antenna coincide. The tube is biased so that both signals must be present simultaneously to produce an output signal. Thus, there will be an output from V2 during a part of only a few radial sweeps per antenna revolution. The output is the radial part of the electronic cross. This signal also goes to V3 pin 1, and is developed across resistors R24, R25, and R26—the same parts which developed the signal for V1. It appears, then, that R24, R25, and R26 are parts common to both blocks. V1 and V2 could be blocked as shown in Figure 7 (R24, R25, and R26 common to V1 and V2, and R23 with V3).

Having a common check point for two different blocks can present problems to the repairman. This would be especially marked when the two input signals were combined so as to lose their separate identity at the check point. In some instances, the signals do not lose their identity when mixed at the check point. In Figure 7, the normal wave form at V3 pin 1 has two distinct portions. If one is missing, the repairman can

31

easily determine that the block associated with that portion of the signal contains the fault. However, in situations where the identities of two signals are lost, it should be specified that, when checking one block output, the output from the other block should be removed. In Figure 7, for example, the output of Block A can be easily checked after pulling V2 or removing the cable at J2.

In the V3 stage, the Track range and azimuth marks are clipped; the output is mixed with the Acquisition range and azimuth marks at R30. All marks then are passed through C13, developed across R28 and R32, then applied to the grid of V4. It appears that there can be a block containing all the parts connected to the plate of V3 and the grid of V4, with two exceptions: R23 should be in the V3 block since it biases V3; for a similar reason, R31 should be in the block containing V4. The Video-and-Mark Mixer chassis would now be blocked as in Figure 9.

Redefining Blocks in Terms of Symptom Information

It is now appropriate to discuss a different type of consideration in establishing trouble shooting blocks. This consideration is the relation of symptom information to system blocking. When something major goes wrong in the system it will show up as a symptom on some external indicator. The repairman must learn the relation of these indications or symptoms to the various channels in the system which can produce them. The M-33 repairman would learn, for example, that when one portion of the electronic cross was missing, the malfunction must lie in the block (either Block A or Block B in Figure 9) that deals with that portion of the cross. He would learn also that, if all track and azimuth marks were missing but video signals were present, then the trouble must lie in those blocks that deal with all mark signals (Block C on Figure 9). Thus, if the electronic cross were completely missing and the acquisition marks were present on the PPI, then the repairman would look for the trouble in Block C.

Again consider Figure 9 to examine the V3 block more closely. All the parts attached to the plate of V3 up through CR4 could, if malfunctioning, affect both portions of the electronic cross. But so could the three resistors, R24, R25, and R26, that have been designated as common to the V1 and V2 blocks. Should these parts be common to three blocks? No, they should be placed solely in the V3 block as shown in Figure 10. This is because, beginning with R24, all parts affect both portions of the electronic cross. The symptom of no cross would lead the repairman to the V3 block and all parts which could cause this symptom should be in that block.

It is not often that the system can be so blocked that an external symptom can be directly related to a single block. The FORECAST analysis does not strive for such close relationships, but the relation of a block to the symptoms it can produce must be considered at some point in the analysis. In the above example it led to redifinition of a block.

To continue our analysis of Figure 10, all the track and acquisition marks are clipped in V4 and then applied to V6, where they are adjusted for equal amplitude. If the signal from V4 is followed, it is seen that it is coupled through C14, then developed across R36, R38, and R37. This

Video-and-Mark Mixer 7614979—Schematic Diagram, Showing Parts Common to More

Block boundaries

O Check points:
Black A—V3 pin 1, pull V2
Black B—V3 pin 1, pull V1
Block C—V4 pin 1

Common parts:
R24, R25, and R26

NOTE: All values expressed in ohms and microfarads unless otherwise indicated.

Block A

PART OF P1

+150V(A)

TRK AZIMUTH GATE FROM MARK GEN.
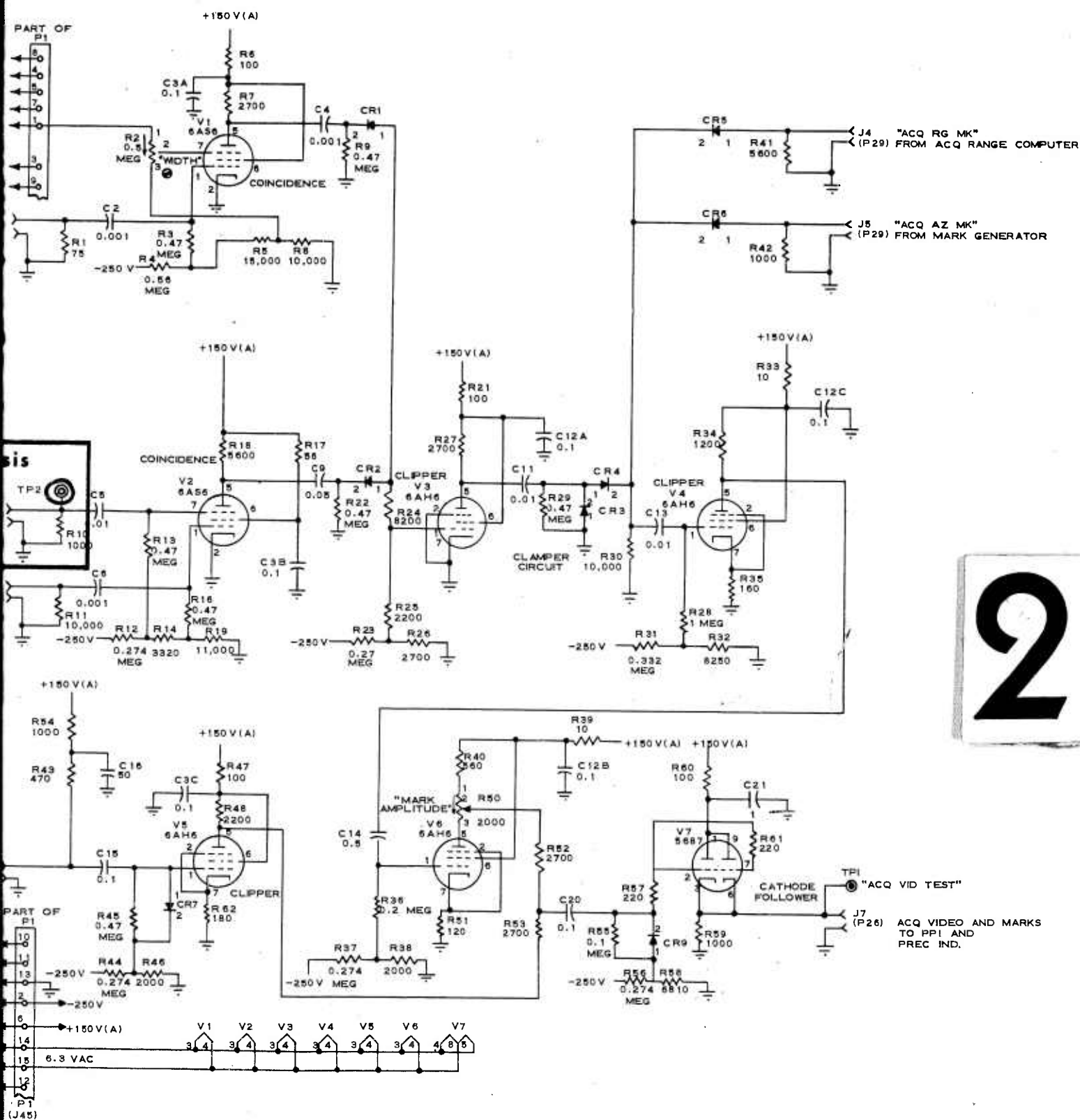
R6 100
C3A 0.1
R7 2700
C4 0.001
CR1
R9 0.47 MEG
V1 6AS6
R2 0.5 MEG
"WIDTH"
COINCIDENCE

J1 (P25) "ACQ TRK" RANGE MARK FROM TRK RANGE COMPUTER

R1 75
C2 0.001
R3 0.47 MEG
R4 0.56 MEG
−250 V
R5 15,000
R8 10,000

Block B

+150V(A)

COINCIDENCE
R18 5600
R17 56
C9 0.05
CR2
R22 0.47 MEG
V2 6AS6

"TRK AZ MK" FROM MARK GEN.

J2 (P27)
C5 0.01
R10 1000
R13 0.47 MEG

J3 (P28) "TRK RG GATE" FROM TRK RANGE COMPUTER

C6 0.001
R11 10,000
R12 0.274 MEG
R14 3320
R16 0.47 MEG
R19 11,000
−250 V
R23
0.27 MEG
C3B 0.1

+150V(A)

R54 1000
R43 470
C16 50
C3C 0.1
R47 100
R48 2200
V5 6AH6
C14 0.5

J6 (P31) "VID IN" FROM SWITCHER MIXER

C15 0.1
CR7
R62 180
CLIPPER
R36 0.2

PART OF P1

R45 0.47 MEG
R44 0.274 MEG
R46 2000
R37 0.274 MEG
R3
200
−250 V

GND
−250 V → −250 V
+150V(A) → +150V(A)

FROM T11-3,4
6.3 VAC

V1 V2 V3 V4 V5

P1 (J45)

1

Figure 9

Block C

Figure 9

Block boundaries

Check points:
Block A—V3 pin 1, pull V2
Block B—V3 pin 1, pull V1
Block C—V4 pin 1
Block D—V6 pin 1
Block E—V7 pin 2, pull V5
Block F—V7 pin 2, pull V6
Block G—TP1

Common ports:
R57, R58, ond CR9—
  Blocks E ond F
C20—Blocks E, F, and G

NOTE: All volues expressed in ohms
and microfarads unless
otherwise indicated.

34
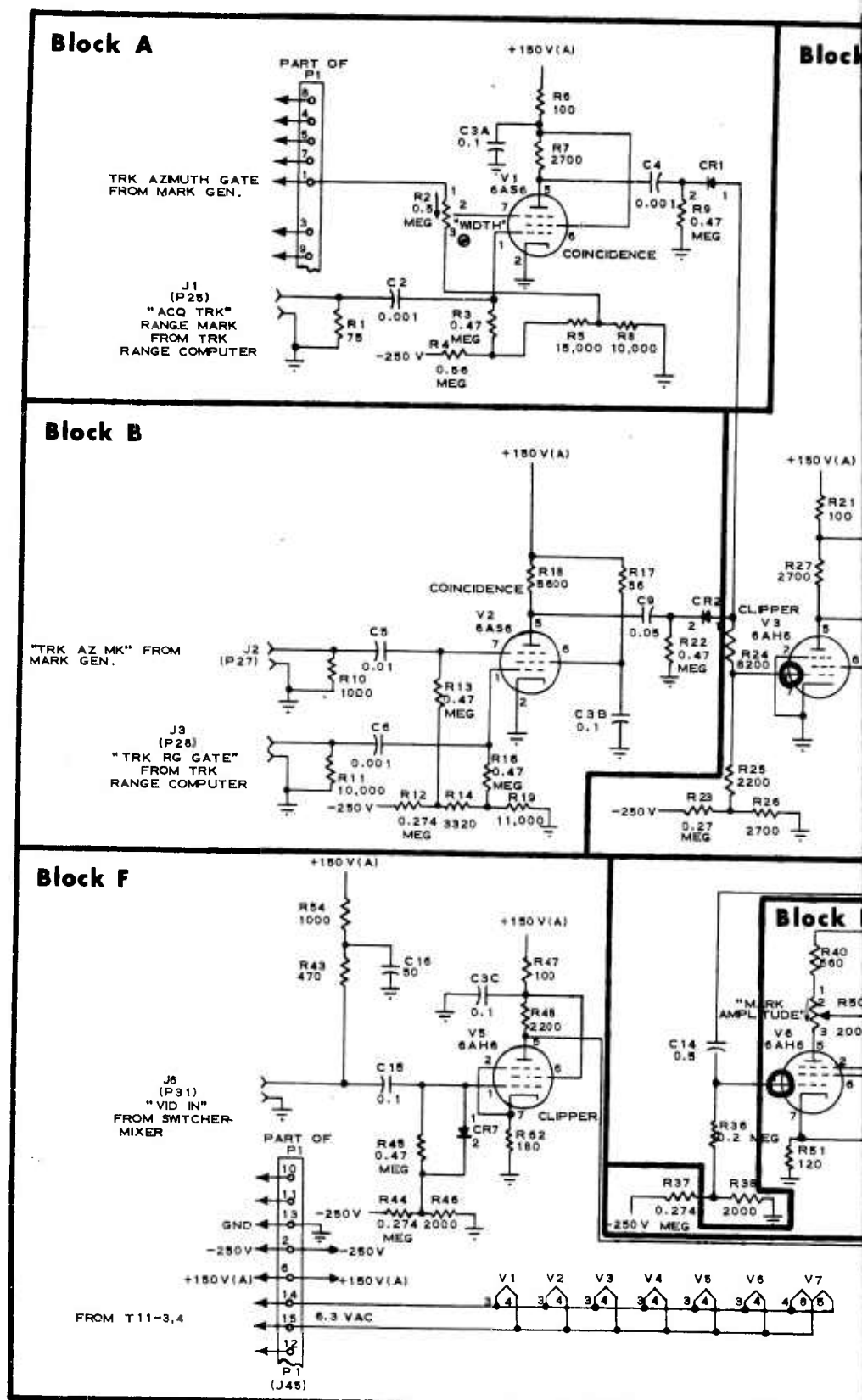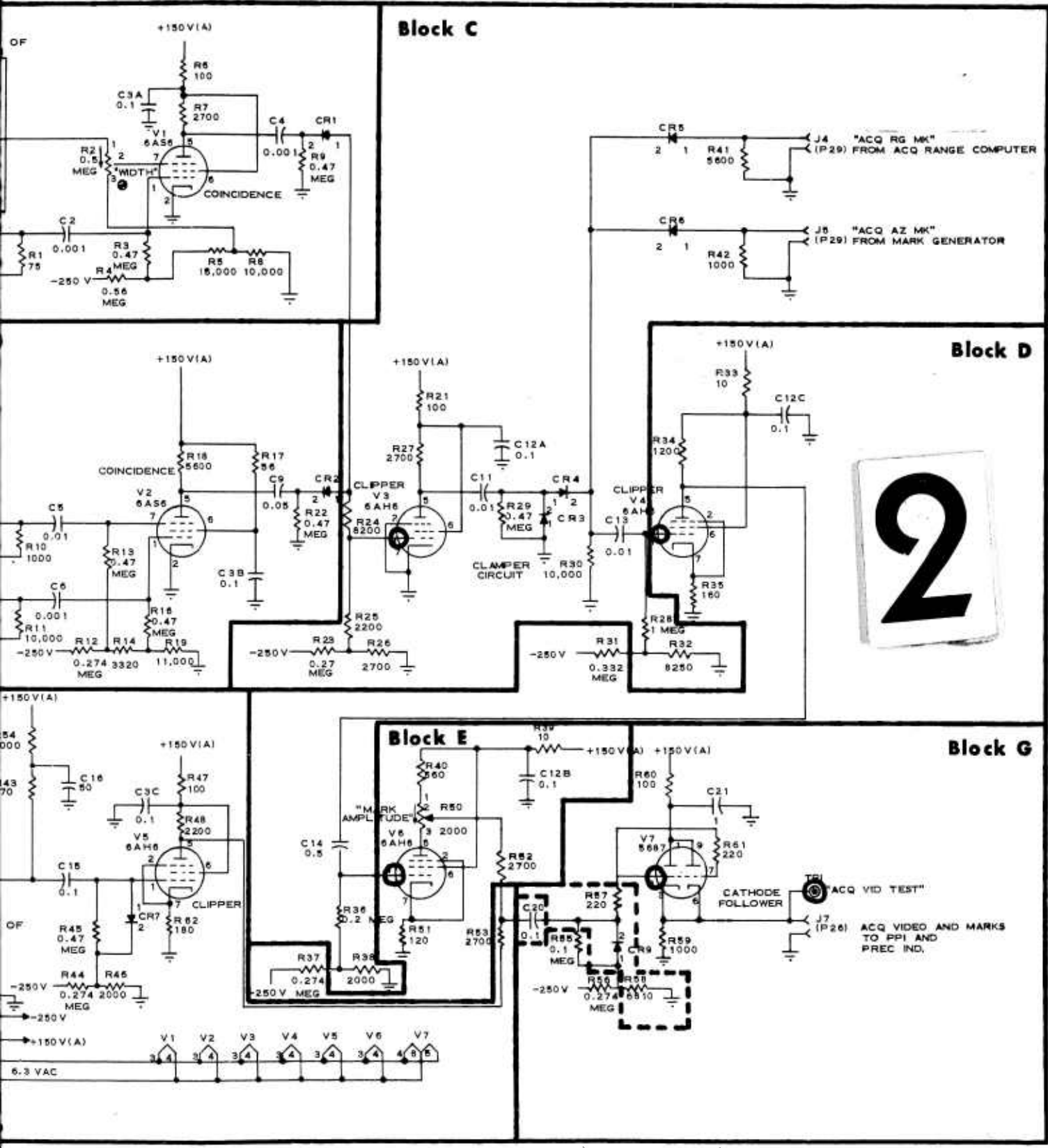
Figure 10

Figure 10

signal can be measured at V6 pin 1. R37 is not included in Block D because it affects the DC bias of V6 which, even if incorrect, would not affect the AC signal at V6 pin 1.

The remainder of Figure 10 presents some interesting blocking problems. It will be noticed that, at the junction of R52 and R53, the marks are combined with video signals coming from V5. The combined signals are then applied to Cathode Follower V7. It would be desirable to have the three stages, V5, V6, and V7 in separate blocks. What is the best blocking procedure to accomplish this?

One approach would be to measure the outputs of both V5 and V6 at the grid of V7. This could be accomplished by specifying that, when measuring the output of V6, V5 should be pulled, and vice versa. Also, it would involve determining what parts to the right of C20 affect the signals at V7 pin 2. It can be readily concluded that parts R57, R58, and CR9 would affect the signal. As the effect of R55 is questionable and would have to be determined by calculation or by empirical check, assume that it does not affect the signal. R56 would not affect the signal at V7 pin 2. Therefore, these stages could be blocked as shown on Figure 10. Here there are three parts that are common to Blocks E and F, and one part, C20, that is common to three blocks (if C20 opens, the outputs of Blocks E and F will be bad; if C20 shorts, the output of Block G will be incorrect, but its inputs will appear correct).

Trade-Off Between Check Point Accessibility and Number of Common Parts

There is nothing technically wrong with the blocking in Figure 10, but it might be well to eliminate some of the common parts, if possible. One way of doing this would be to select another check point—V5 pin 5 plus R53, for example. Here check point accessibility would be sacrificed to eliminate common parts. It might be decided that the additional time required to make a measurement at this point would be more than offset by the ease of interpreting the measurement and determining which parts to check if bad readings were obtained.

A consideration in this connection is the procedure the repairman might use to check out the parts within a block. For example, suppose that the check point for Blocks E and F were at V7 pin 2. Assume further, that the repairman has accurately interpreted a bad reading here as indicating that some part(s) in Block F is at fault. He would then, according to FORECAST procedures, begin applying chassis trouble shooting techniques and, after checking tubes, would check the DC resistance readings at each pin of V5 on the cold chassis. It will be noticed that not all parts can be checked out in this fashion. The ones that can not are called "hidden parts" and have to be checked individually or at some tube pin located in another block. Parts R57, R56, and CR9 are hidden parts with respect to Block F because resistance measurement at V5 pin 5 would not be affected by the state of these parts.

Thus, there are at least three reasons why we would define Blocks E, F, and G as shown in Figure 11: (1) to eliminate common parts, (2) to make interpretation of the measure easier, and (3) to make simple

chassis trouble shooting procedures applicable for checking most of the parts within a block.

Review of Principles Used in Analysis of Video-and-Mark Mixer Chassis

A number of important principles were demonstrated during the preceding analysis:

(1) Blocks should be arranged so that all their parts are on the same chassis. This principle was applied most directly to the treatment of chassis inputs as exemplified by the treatment of part R10 in Figure 5 (see page 26).

(2) Check points should preferably be selected at the ends of cables or at tube pins, to facilitate check point accessibility. A deviation from this procedure was made to eliminate common parts and to facilitate chassis trouble shooting (see Figure 6 and page 28). The objective in this instance especially, and in all others to some extent, was to arrange blocks so that practical trouble shooting techniques could be easily applied.

(3) When possible, the blocks should be so arranged that there are no common parts.

(4) There should be no reluctance to select check points where two or more signals are combined. This situation should be handled by specifying the procedures for removing the unwanted signals from that point. It does not matter what the signal is at a given point, so long as it can be accurately used to check out a particular portion of the system.

(5) Where possible, symptom information should be used to help determine the boundaries of the blocks. This information may not be available during the initial analysis, but eventually it must be. It should then be used to assess and, if necessary, redefine the block boundaries.

There are a few features of the Video-and-Mark Mixer chassis which are not characteristic of most chassis. For one thing, the circuitry is so arranged that it is possible for each stage to become a block. Generally this is not possible, and sometimes two to three stages have to be combined into one block. Secondly, this chassis contains a lot of mixing stages where various inputs are combined without losing their identity. This means that symptom information could be used to isolate the trouble directly to one of a small number of stages. One particular symptom was mentioned (complete absence of the electronic cross) which could be used to isolate the malfunction to Block C. Generally, symptoms are used to localize the fault to a chain of blocks. Then, by block-output checks, the trouble is further localized.

MULTIPLE-OUTPUT BLOCKS

Check Point Location vs. Measurement Procedures

Up to this point, fairly simple blocking situations have been discussed. Some of the more complex situations will now be considered. The M-33 4-kc Oscillator provides a good vehicle for these problems.

Block boundaries

Check points:
Block A—V3 pin 1, pull V2
Block B—V3 pin 1, pull V1
Block C—V4 pin 1
Block D—V6 pin 1
Block E—V5 pin 5, plus R53, pull V5
Block F—V5 pin 5, plus R53, pull V6
Block G—TP1

NOTE: All values expressed in ohms and microfarads unless otherwise indicated.
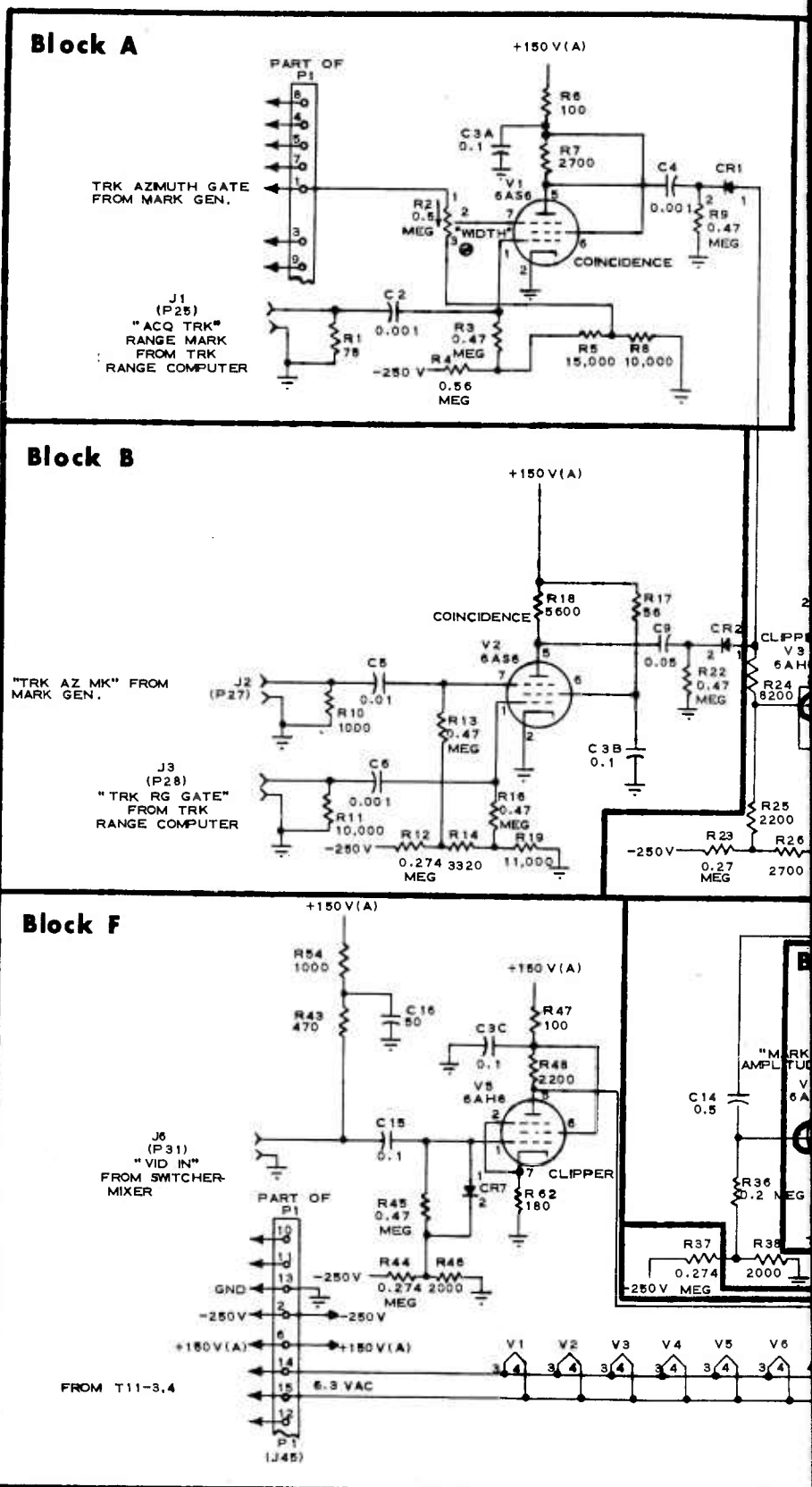
Figure 11
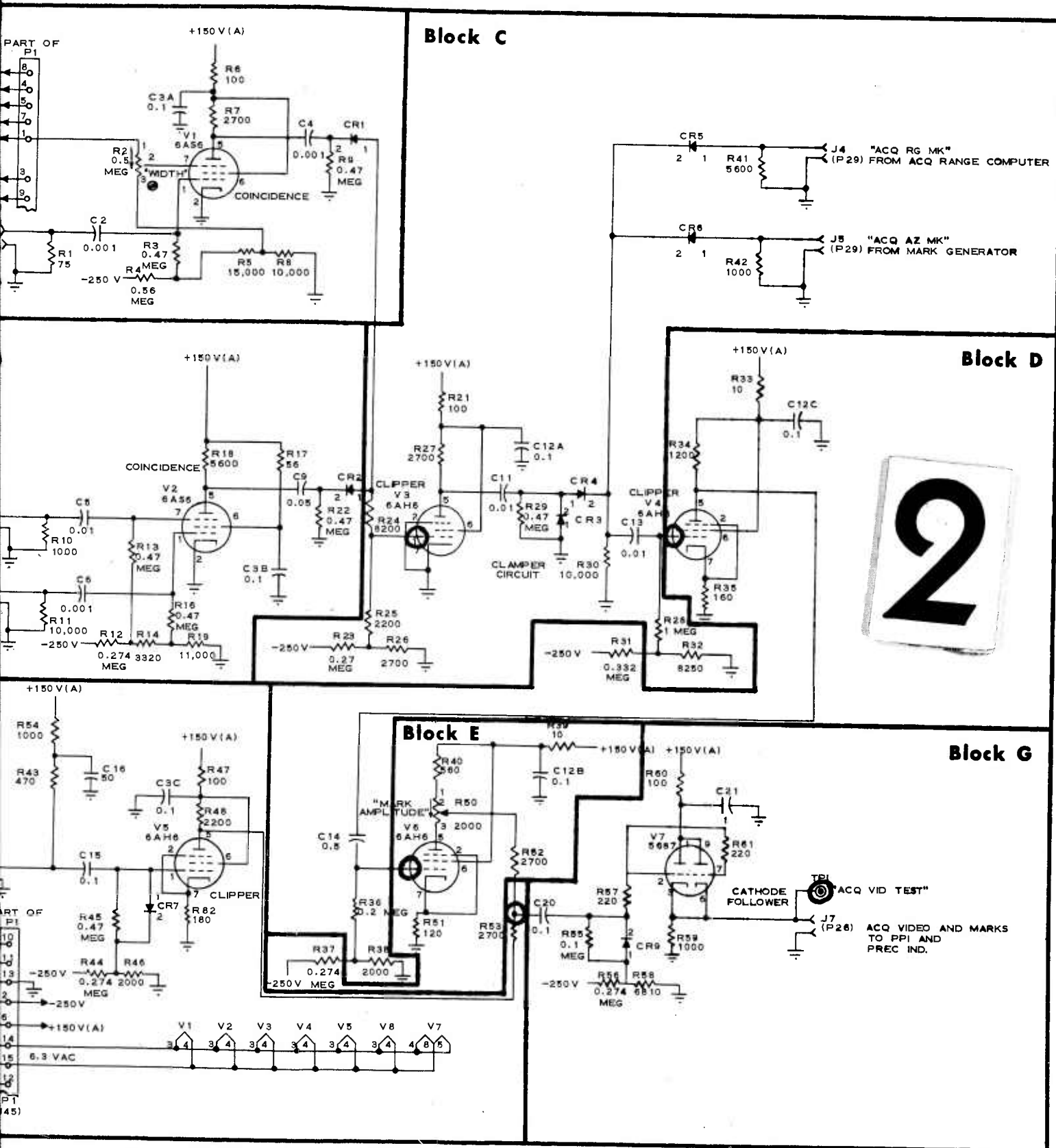
Figure 11

Block boundary
Check points
Common parts
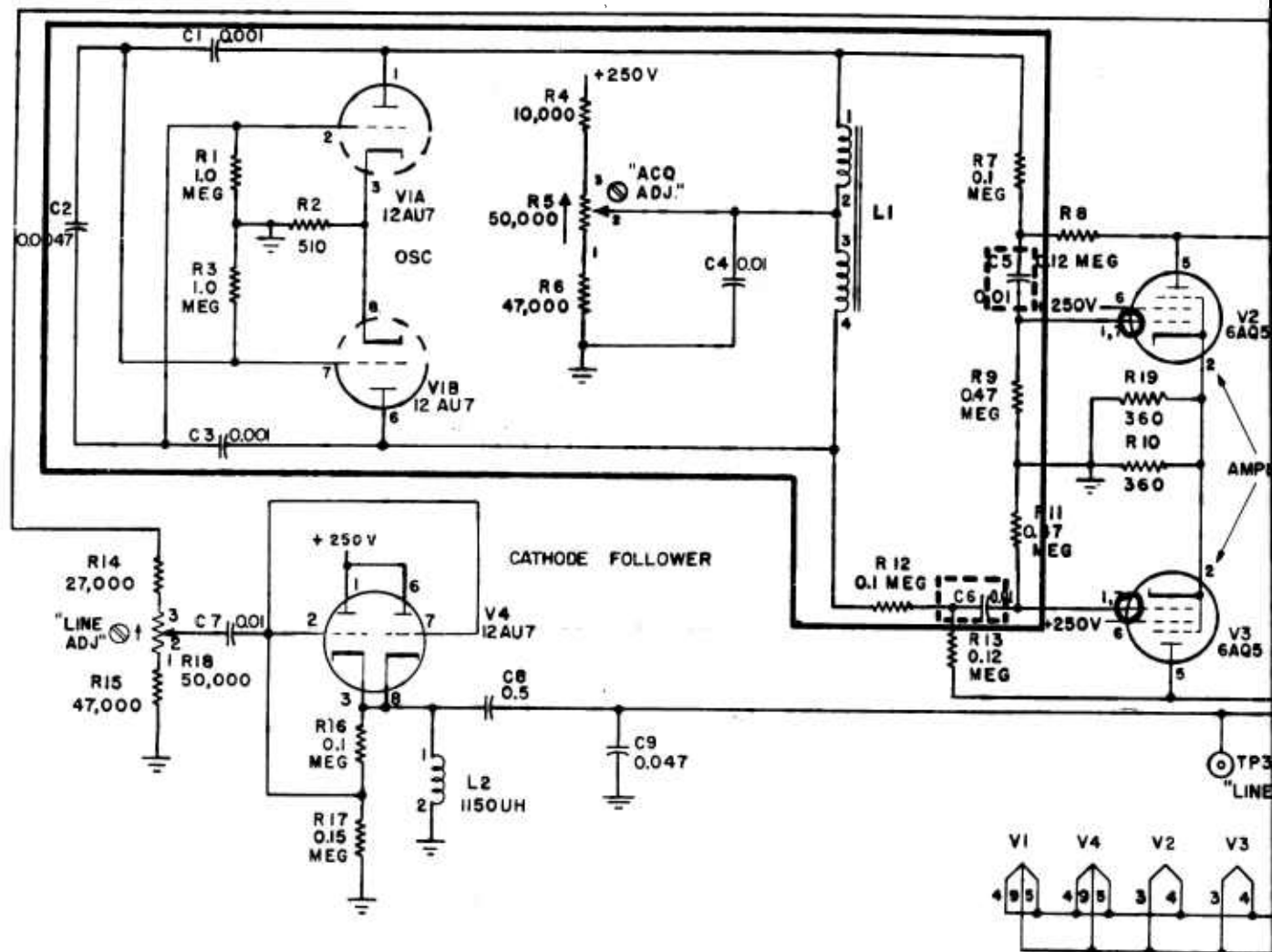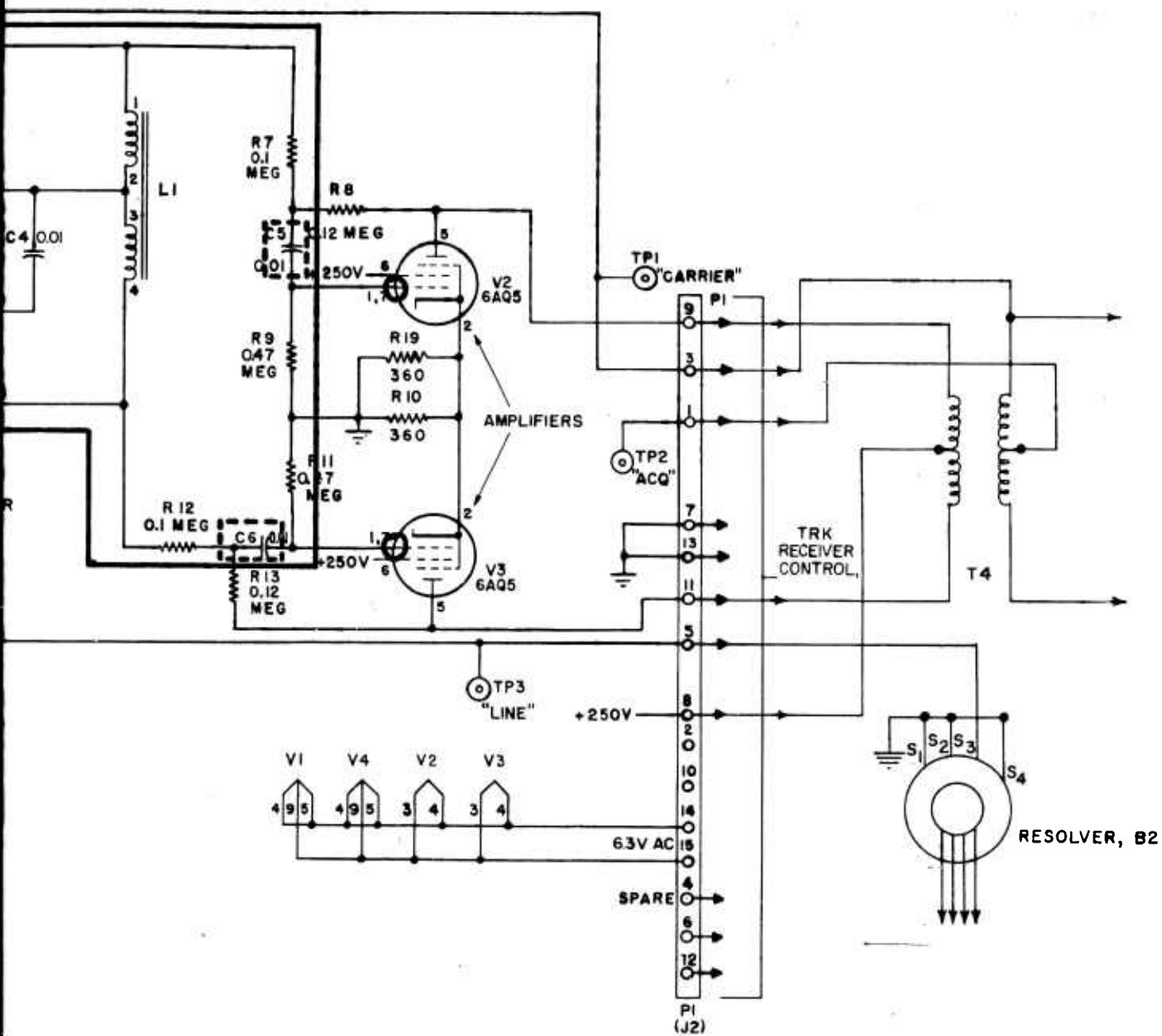
Figure 12

Figure 12

NOTE: All values are expressed in ohms and microfarads unless otherwise indicated.

The purpose of the 4-kc oscillator is to provide reference signals that are used to provide azimuth information. Functionally, the oscillator consists of three stages—an oscillator, a push-pull amplifier, and a cathode follower stage. In Figure 12, dual triode V1 is used to generate the 4-kc signal. The signal frequency is determined by the L-C combination of L1, C1, C2, and C3. Resistors R4, R5, and R6 are used to regulate the voltage level of the output signal. The two outputs of V1 are each fed to one half of the push-pull amplifier V2 and V3. The amplified signals are combined in T4, and then distributed to various portions of the system.

To begin the analysis, it is obvious that both sections of V1 are necessary to produce the desired signal. Therefore, they should be located in the same block. The two outputs of V1 could be measured at the grids of V2 and V3, respectively. It will be noticed, however, that part of the signal output from V2 is fed back through R8 and C5 to the V2 grid. A similar feedback arrangement exists for V3. Therefore, a check point at V2, pin 1, would be affected by two signals, one from V1A and the other from V2. By pulling V2, the feedback can be removed from this check point, and a measure of the V1A output only can be obtained. In similar fashion, the output of V1B can be measured at the grid of V3, provided that V3 is removed from the circuit. What parts are measured at these check points? In addition to all the parts, including and to the left of L1 on Figure 12, parts R7, R9, R11, and R12 would be checked. The possibility that capacitors C5 and C6 might be open would also be checked. If these parts were shorted, the AC signal might not be affected at the check points, but the output of the amplifier block would be. Therefore C5 and C6 are common parts.

According to the above analysis, a block could consist of the parts contained within the block boundary shown on Figure 12. This block would have two outputs, and to check out the block two tubes would have to be pulled. Having a multi-output block is quite typical and should cause the analyst no concern. But the necessity for pulling two tubes to check the outputs may be troublesome from a practical standpoint. Can the necessity for this be eliminated in the present instance?

It is not always desirable to measure outputs at the grid of a tube. Some outputs are best measured at the plate or the cathode of a tube. In the present example, the oscillator outputs could be measured at the plates of V1A and V1B respectively. Measures at these points would not require pulling V2 and V3. This would seem to be the preferred way of blocking V1A and V1B (see Figure 13).

Chassis Substitution

The oscillator signals are amplified by V2 and V3. The secondary of T4 is connected to the various chassis in the system that employs the 4-kc signal. It will be noticed that there are two test points, TP1 and TP2, which are connected to the secondary of T4. These points are for checking the output from the oscillator chassis. However, the secondary of T4 is connected to a number of terminating resistors and one coil, each of which is located on a different chassis. If one of these parts goes bad, the secondary load could change and this would reflect back

into the primary. The result is that the signal at TP1 and TP2, and at any point connected to the primary of T4, can be affected by malfunctions in other areas of the system. If the malfunction in these other areas is in the nature of an open part, then probably the effect will not be noticed at TP1 or TP2.

One way to handle this problem is to determine what parts are connected to the secondary of T4, and include them in the block with T4, V2, and V3. This would make for a cumbersome trouble shooting block that contained parts scattered all over the system. An alternative would be to disconnect T4 from the circuit and determine what the resulting signal should be at pins 9 and 11 of P1. A further examination of this possibility would reveal that T4 cannot be readily removed from the circuit. A third alternative would be to open the secondary of T4 and determine what the reading at TP1 should be under these conditions. This would be a good procedure except that the secondary cannot be easily opened. (Incidentally, here is an instance where a system, if engineered for the repairman, would contain some easy way of opening the T4 secondary.)

There is no way to block V2 and V3 so that the output of the block can be readily checked. A roundabout procedure would be to employ chassis substitution. If an external symptom indicated that something was wrong with the 4-kc signal, the oscillator output, Block A on Figure 13, could be checked. If this were good, then the repairman could assume that the trouble was in Block B that contains V2 and V3. This block can be checked by substituting a new 4-kc oscillator chassis. If the trouble still persists, it must lie in T4 or in one of the parts connected to the secondary of T4. After checking T4, the repairman would have to make a series of continuity checks over the 4-kc distribution system until the trouble was found. Block B would also include parts R14, R18, and R15, which are at the input to V4 but are connected to the secondary of T4.

Cathode Follower

There are other parts on the 4-kc AF Oscillator chassis which have not as yet been placed into a trouble shooting block. On Figure 13, these are the parts associated with V4, a cathode follower stage.

Tube V4 receives its input through pin 3 of the P1 plug. This pin 3 is connected to the secondary terminal of T4, located in the track receiver control cabinet. Functionally, the cathode follower is like other loads connected to the T4 secondary, and will behave as these loads do. That is, a malfunction associated with any one of the loads will result in a bad input to the cathode follower stage.

The input to the cathode follower stage can be measured at V4 pin 2. As seen on Figure 13, this input could be affected by malfunctions in R14, R15, R18, and C7. Notice, however, that regardless of how the three resistors malfunction, the input at V4 pin 2 would be incorrect. Therefore, these three parts should be placed in the V2. V3 amplifier block. Capacitor C7 will affect either the input to V4 or the output of V4, depending on how it malfunctions. Therefore, C7 should be designated a common part.

Determining Trouble Shooting Blocks for the 4-kc AF Oscillator Chassis
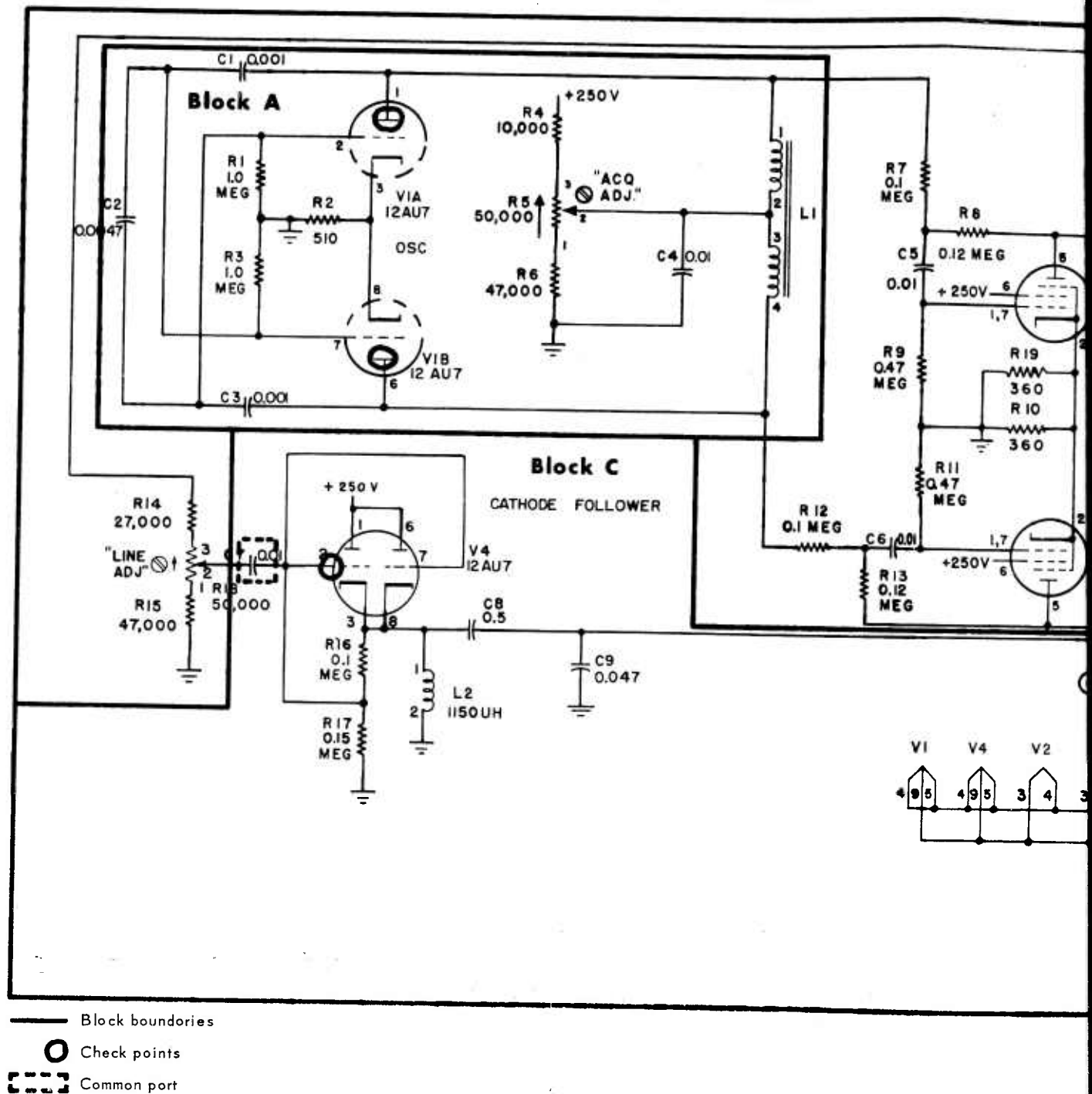
Block boundaries ————
Check points O
Common port [- - -]

Figure 13

Oscillator Chassis

Figure 13
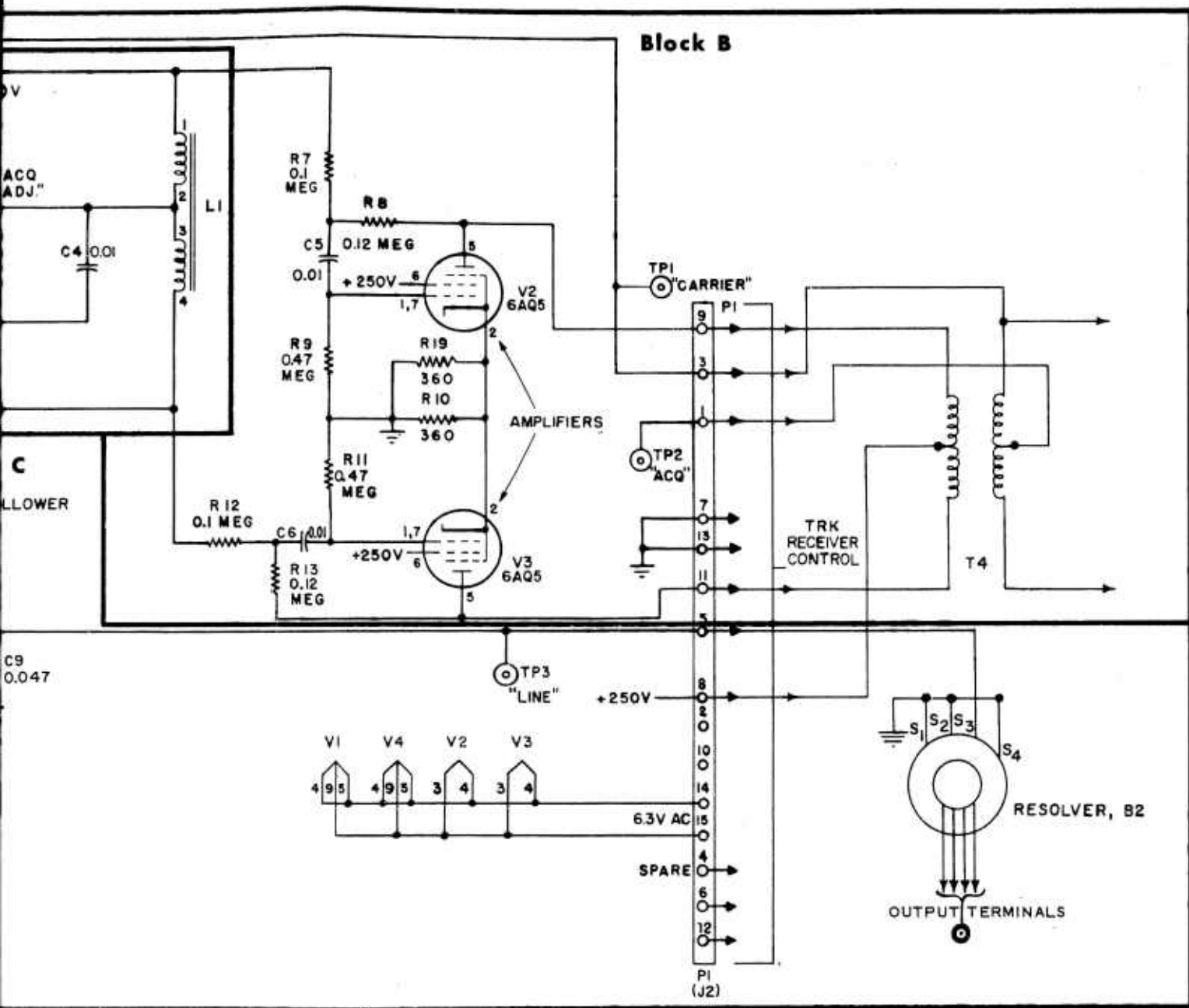
41

In the present example, the output of V4 goes to a line slew resolver, and this resolver is the only load for the cathode follower. Thus, it should be considered a part of the cathode follower block because a malfunction in the resolver would affect the V4 output. The cathode follower block should include both V4 and the resolver, and the output check point for the block should be at the output terminals of the resolver.

TRANSFORMER-COUPLED STAGES

General Blocking Procedure

We have seen in the preceding section that the presence of transformers can make blocking quite difficult. This section describes more fully the FORECAST procedures for dealing with these difficulties.

A fundamental characteristic of electronic systems is the relative insensitivity of early stages to malfunctioning later stages, when stages are serially connected and are without feedback. Signals appearing on the grid of a grounded cathode amplifier are not usually affected by malfunctions occurring in the plate circuit. This characteristic permits easy fault location and forms a basis for any systematic procedure for trouble shooting electronic equipment.

Attention is now directed to transformer-coupled circuits. Transformers themselves are such useful parts that they appear often in electronic circuits. Consider simple transformers, having one primary and one secondary winding. It is important to consider what happens in the primary circuit of a transformer as a result of a malfunction in the secondary circuit. This depends, in part, on the turns ratio. The step-up type of transformer, often used for interstage coupling, takes a relatively low voltage at the primary terminals and steps it up to a much higher voltage at the secondary terminals. The secondary terminals will have some sort of load connected to them. Often a resistor shunts the secondary terminals. The question is, what effect will the condition of this resistor have on the voltage at the primary terminals?

Seen from the primary terminals, the load in the secondary will be greatly reduced. This means that a one-ohm change in the secondary resistance will look like a fraction of an ohm in the primary. The effect that this will have on the primary will depend upon the remainder of the primary circuit.

With step-down transformers, on the other hand, a one-ohm change in the secondary will look like more than one ohm in the primary. In both cases, step-up or step-down, it is evident that changes in secondary loading will have an effect in the primary. Because of this, transformers do not have that isolating property which characterizes vacuum tubes. Hence, it is not possible to block circuits containing transformers as if the transformers were isolating elements. In blocking electronic circuits which contain transformers, the transformers themselves must be considered to be bilateral circuit elements, much like resistors. It is not permissible to block the circuit so that the primary of the transformer lies in the first block and the secondary lies in the next block. The transformer must lie wholly within the first block, and parts in the

secondary circuit of the transformer that can affect the output check point of that block must be included in the same block with the transformer.

Transformer Blocking: An Example

By way of an example, consider the Acquisition IF Amplifier from the M-33 (see Figure 14). In this circuit, it is desirable to have V6 and V7 in separate blocks. Transformer T7 links the signal from V6 to V7. In blocking, there are always two interrelated questions that must be answered: Where is the check point, and where is the boundary of the blocks? Let pin 1 of V7 be selected as the check point for the block containing V6. Now, locate the boundary of the V6 block to the right of R48, putting T7 into the V6 block. This represents the general solution to blocking transformers; namely, all parts attached to both the primary and secondary of the transformer affect the output and should be placed in the same block. If the boundary of the V6 block were made to pass through the center of the transformer, placing the primary in the preceding block and the secondary in the following block, then the rule that every part affecting the output of the block must be contained within that block would have been violated.

Suppose the cut had been made so that the transformer were in the V7 block. By doing this, the check point could be pin 5, V6. If this were the case, and the primary shorted, a bad signal would appear at V6, pin 5. But since the transformer was placed with V7, the transformer would not be expected to originate the trouble. Now, as a matter of fact, if pin resistance readings were taken on V6, the short circuit would be discovered and, despite the fact that the transformer was placed in V7 block, the trouble would be found. However, a more subtle type of malfunction could occur in which the condition of the transformer could not be determined by a resistance check of the primary. If the secondary should short, for example, the signal appearing at V6 pin 5 could be sufficiently changed to lead us to assume that the trouble was in the V6 block rather than in the V7 block. Therefore, we do not block the transformer in this way.

To be sure, in some types of circuits the interaction between primary and secondary circuits is so complicated that it is not possible to block them at all, and an entirely different approach to trouble shooting must be employed. A fairly standard technique is to substitute, for the normal load on the secondary of a transformer, a dummy load that is known to be good. If the trouble persists, then it is assumed to be located in portions of the signal chain coming before this transformer.

TREATMENT OF FEEDBACK CIRCUITS

General Blocking Procedure

One does not proceed very far in the analysis of complex electronic systems before being faced with feedbacks. Broadly speaking, feedback refers to circuitry in which part of the output signal is joined to the input signal. The various technical aspects of feedback circuits will not be

IF Amplifier

Block boundary
Check point

1
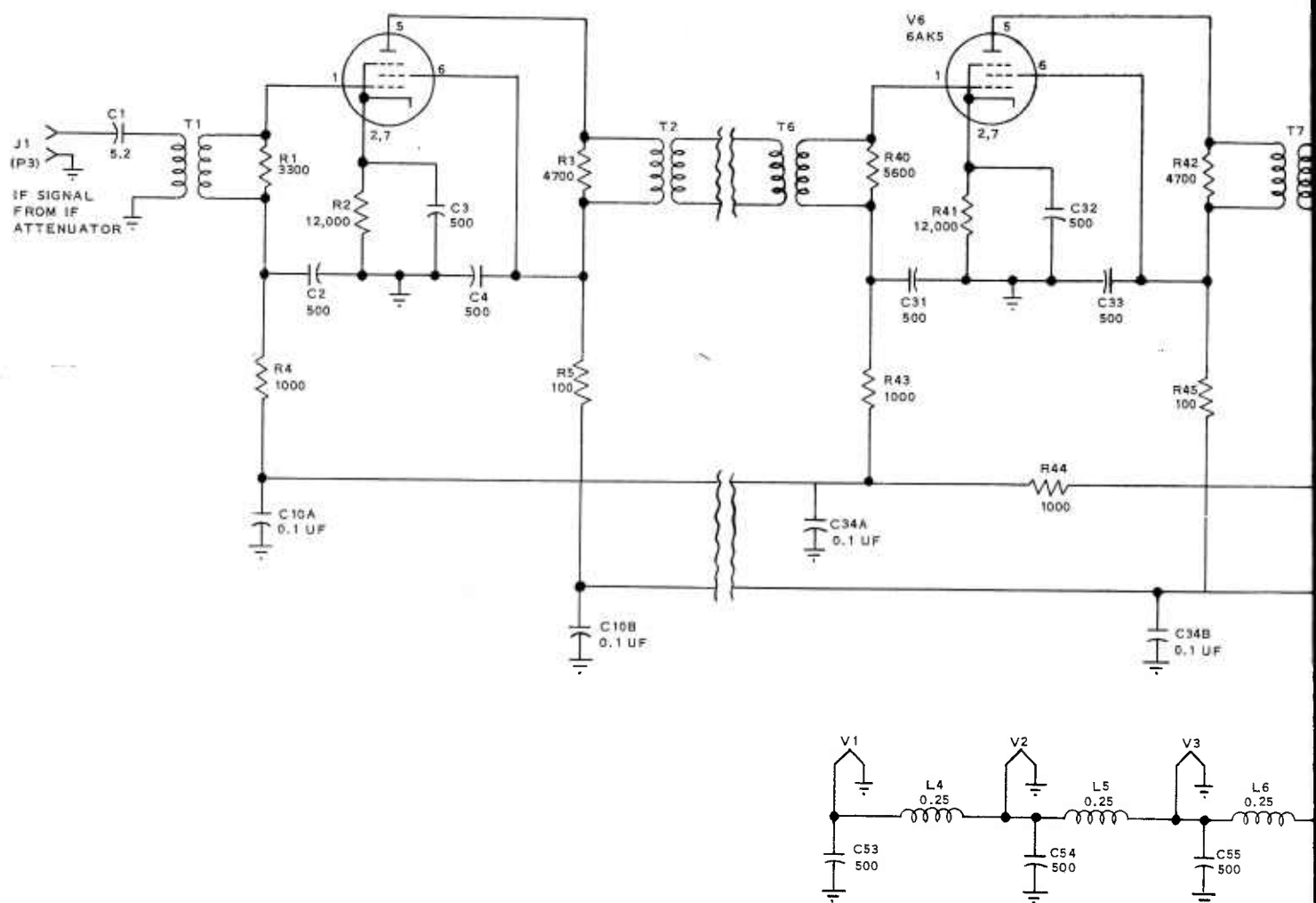
Figur

IF Amplifier

IF Detector
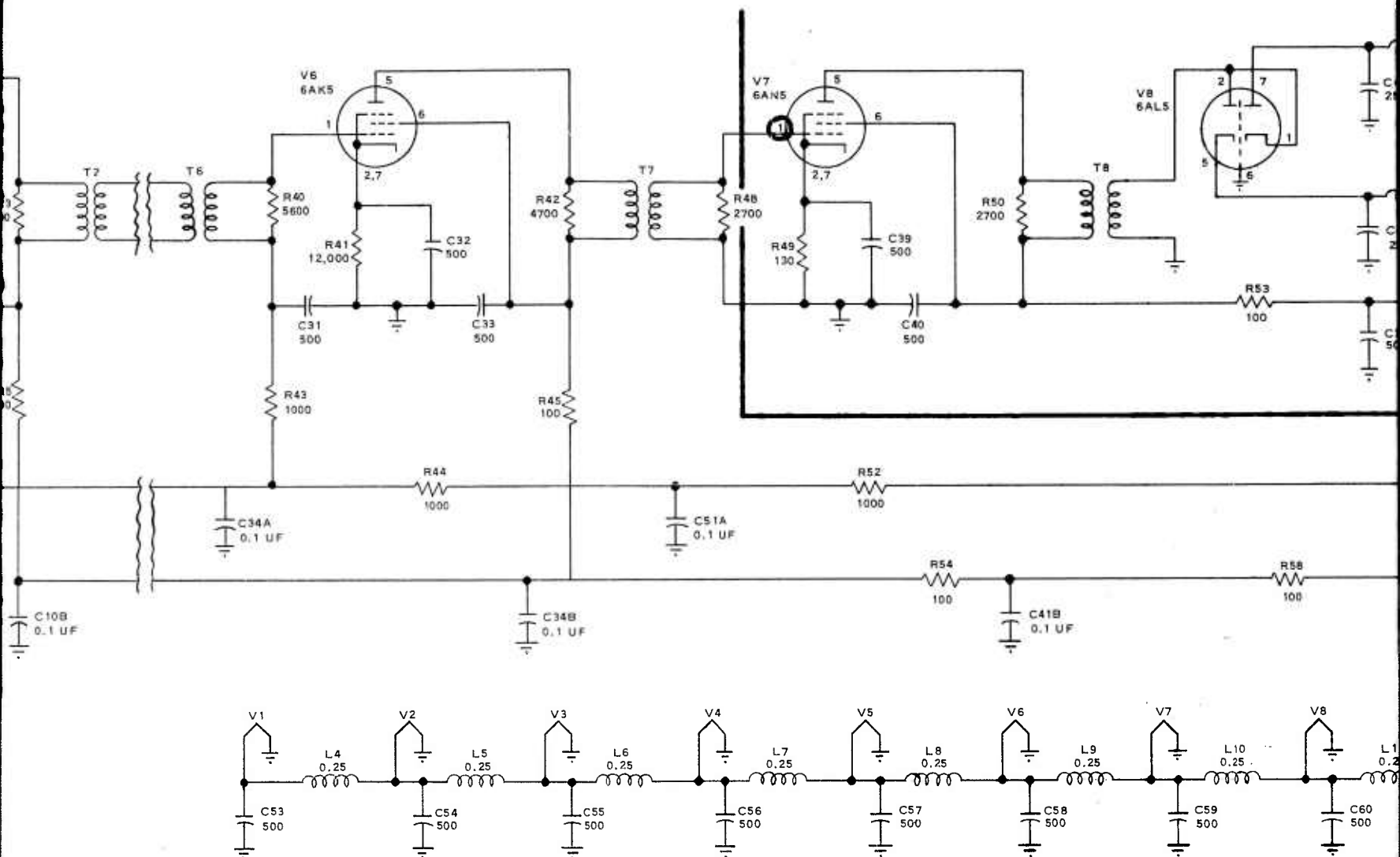
Figure 14

IF Detector
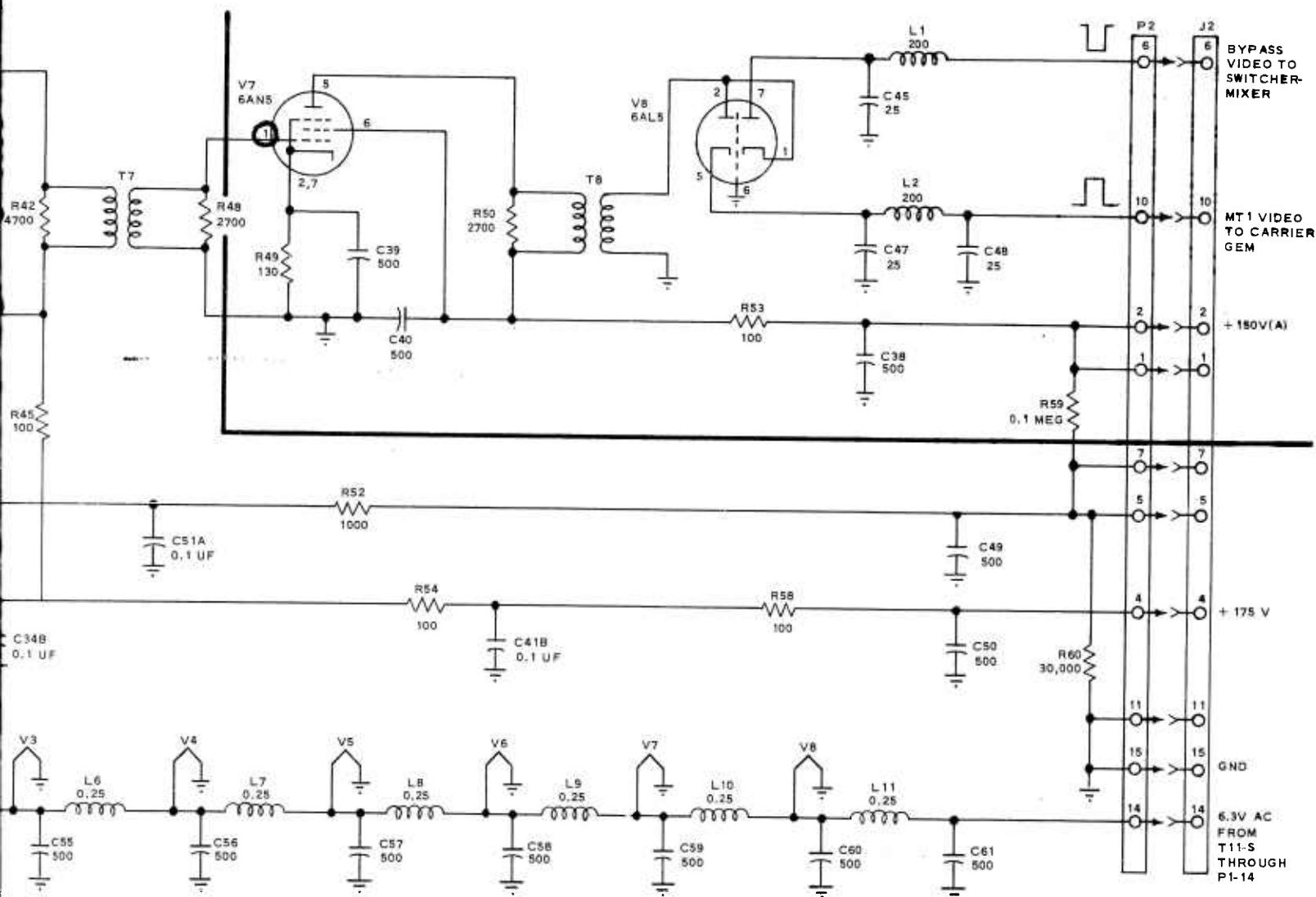
NOTE: All values are expressed in ohms, micromicrofarads, and microhenries unless otherwise indicated.

Figure 14

3

discussed in any detail or with any significant breadth. Rather, how the FORECAST Trouble Shooting Method of Analysis can be used to handle the feedback problem for repairmen will be shown.

Feedback circuits are required for various reasons: stability, broad-band frequency response, impedance matching, reduction of nonlinear distortion, frequency generation, and gain control—to mention a few. There is a kind of circularity which confronts the repairman in feedback circuitry. For example, suppose, as in Figure 15, a signal is sent through Blocks A, B, C, and D, then on out through the rest of the system. In addition, suppose that the signal that is sent on to D is also sent to E, after which it is returned to A. Now, suppose that C provides a bad output. Also, suppose that the signal into A from alpha is good. All that can really be said with any confidence is that one of the blocks—A, B, C, or E—is bad. In fact, if the outputs of all those blocks were measured, it would be found that all of them were bad. This follows from the general rules of blocking—if one bad signal enters a block, the output must be bad. C has a bad output, requiring E's output to be bad, making A's output bad, making B's output bad.

Where is the malfunction that produced this merry-go-round? Who can tell? Fortunately, things are not quite hopeless; it can be determined. It is possible to locate the malfunctioning part by breaking the feedback loop. This is done by opening the connection which joins E with A. Naturally, this will not correct the trouble, but it will permit locating the fault, provided the open-loop response has been obtained beforehand by the systems analysts who determined the trouble shooting check points. That is, by recognizing the presence of feedback loops, it is possible to obtain the open-loop response of the blocks within the circuitry before equipment malfunction, so that they may be treated as if they were not in a feedback circuit when a malfunction is present. An illustration might be helpful in this connection.

Block Diagram Showing a Feedback Loop
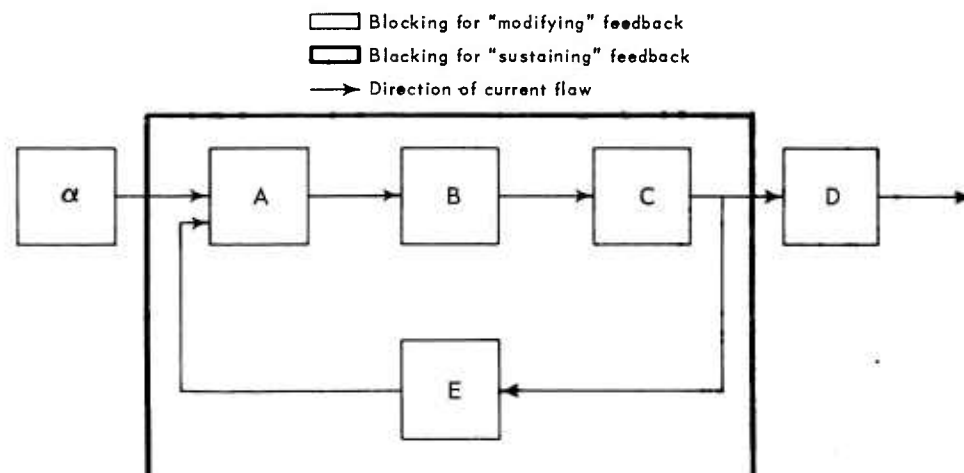
Figure 15

Blocking Feedbacks: An Example

Figure 16 is a diagram of a very simple sort of feedback R/C coupled amplifier. This two-tube amplifier has feedback around only the last stage, R4/C3 being the parts affecting the feedback. The signal enters V1 on the control grid, is coupled from the plate of V1 through the coupling capacitor C2 to the grid of V2, and to ground through the grid resistor R3. The signal appearing at the grid of V2 from V1 is amplified and coupled from the plate of V2 through the coupling capacitor C5 to the output terminal. In addition, the plate voltage is coupled back to the grid resistor by means of C3 and R4, the feedback coupling network. A positive going signal on the grid resistor from V2 produces a negative going signal at the plate of V2, that is dropped across the voltage divider consisting of R4 and R3, the grid resistor as a negative going signal. As the input signal and the feedback signal are of reverse polarity, the feedback is called negative. The output is fed back in such a way that it tends to reduce itself. Clearly, by varying the magnitude of R4 with respect to R3, one can obtain differing amounts of feedback.

Assume that the ratio of R4 to R3 is such that when the two signals combine, their sum is almost enough to saturate V2. Under this

Schematic Diagram Showing Blocking Treatment of Plate-to-Grid Feedback
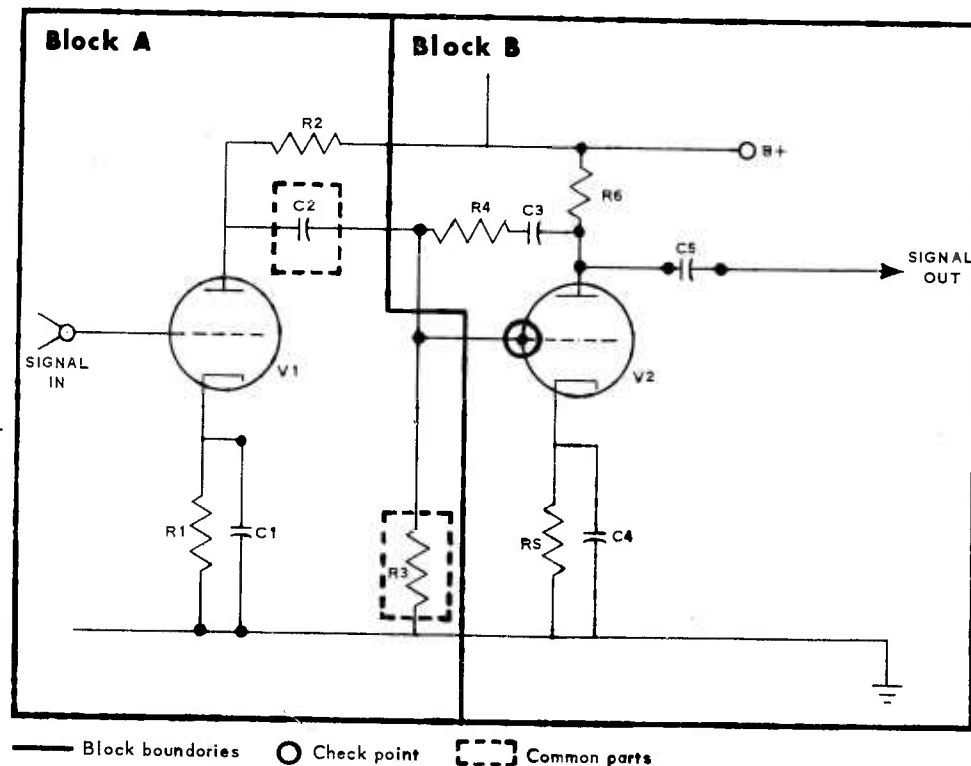
Figure 16

condition, if the feedback connection should become lost, V2 will saturate and the output of the stage will be bad. On the other hand, if the check point were made at the grid of V2, as before, and the signal was not right, there would be no way of telling from the measurement of the signal at that point which signal was to blame, the feedback or the signal from V1. Suppose the signal level increased from V1. This could mean that the feedback voltage had decreased, or it could mean that the signal voltage had increased. It could not be determined positively. However, the feedback connection can be deliberately broken when the equipment does not have a malfunction in it (for the purpose of obtaining check point wave forms). When a malfunction does occur, it will then be possible to break the feedback to determine if the trouble is in the preceding or the following stages.

It is not necessary to unsolder the feedback connection to break it. In the example, it is necessary only to remove the tube V2 from its socket and measure at the grid terminal of V2. The signal measured there will be the signal without feedback and will enable the repairman to tell if the trouble lies in parts associated with V1 or in those associated with V2.

With respect to blocking this circuit, it should be possible to include V1, its cathode resistor R1 and bypass capacitor C1, its plate load resistor R2, the coupling capacitor C2, and the grid resistor R3 of V2, in Block A, placing all the remaining parts in Block B. The check point for Block A is the control grid of V2. To check the output of Block A, it is necessary to remove V2. This done, the feedback signal will not be present at the check point, and evidence of the proper operation of Block A can be obtained.

Feedback Circuitry Types

The FORECAST approach categorizes feedbacks into two general classes called "sustaining" feedbacks and "modifying" feedbacks. The techniques for analyzing circuitry into trouble shooting blocks will depend on which type of feedback is considered.

The term "sustaining" feedback refers to circuitry in which, if the feedback loop is broken, there will be no main signal. In other words, there will be no open-loop response. In the block diagram of Figure 15, for example, if Block E were to fail so that no signal were sent from E to A, and as a result no signal at all were sent to B, and so on, this would be identified as a sustaining type of feedback. Oscillators, in general, have this type of feedback.

On the other hand, sustaining feedback circuitry cannot be blocked by opening the feedback loop and determining the open-loop response. Such circuitry must be handled so that the feedback loop lies within the block. In the example described for Figure 15, this would mean that if the feedback from Block C to Block A is a sustaining feedback, then Blocks A, B, C, and E must all be contained within one trouble shooting block. Figure 13, the M-33 4-kc oscillator, contains another example of the sustaining feedback. Here V1A and V1B make up the oscillator stage and must both be contained within the same block.

A "modifying" feedback refers to circuitry in which, if the feedback loop is broken, the main signal will be disturbed but will not be completely missing. In these instances, the open-loop response of the circuit can be used to check out the circuit. Again referring to Figure 15, if Block E were to fail so that no signal were sent to Block A, and as a result the signal from A to B, and so on were changed but not absent, then this would be identified as a modifying type of feedback. In circuits having this type of feedback, trouble shooting Blocks A, B, and C can be created, but it must be specified that the feedback must be broken before these blocks can be checked.

An example of a modifying feedback would be the R4/C3 network in Figure 16. Here, if the feedback were removed, depending on the nature of the input signal from Block A, Block B would continue to have an output. From the standpoint of normal system operation, this open-loop signal would be incorrect. However, this signal could still be used to check Block A, so long as the "normal" open-loop signal was known.

The reader may be aware that there is a class of feedbacks termed "stabilizing" feedbacks. These are used to prevent some type of over-response of the system. This feedback category has been subsumed under the modifying feedback heading. However, the analyst should determine whether a modifying feedback is being used for stability purposes. If so, then it must be determined whether system damage will occur if this stability feedback is removed. For example, feedback loops may be used to reduce the response time in some portion of the system. Opening these loops may result in excessive oscillatory behavior and system damage. Naturally, the analyst must determine if such damage is likely to occur. If so, the blocking must be arranged so that the feedback does not have to be broken to check the blocks.

In summary, sustaining feedback circuitry cannot be blocked by determining the open-loop response. Such circuitry must be blocked so that the complete feedback loop lies within the block. Modifying feedback circuitry can be blocked by opening the feedback loop to determine the open-loop response. In this circuitry, feedback loops might become blocks in themselves (see Figure 15). Stability feedbacks are a subclass of modifying feedbacks but must be included within one block if breaking the feedback will cause system damage.

Section 3

THE DETERMINATION OF SYMPTOM AND CHECK POINT INFORMATION

SYMPTOM INFORMATION

Use of Symptom Information

After the circuit analysis described in Section 2 has been completed, all electronic parts of the system can be described as being located in one or more trouble shooting blocks. The next step in the analysis is to determine the relationship between these blocks and the various common symptoms which may appear on scopes or meters, or during control operations. Understanding of the manner in which symptom information is treated in the FORECAST approach should be furthered by a review of the first two steps of the FORECAST trouble shooting procedure.[1]

The initial FORECAST trouble shooting step involves the collection of display and/or operational symptoms. To obtain these symptoms, the repairman attempts to (1) energize the system completely, (2) place all visual displays in an operational condition, and (3) operate the system in all operational modes. During this activity these questions are asked:

What is missing or wrong with the external visual displays?

Under what operating conditions are the displays abnormal?

What operations will the system not perform properly?

This operational checkout procedure terminates either with a decision that the system is in good working order or with a description of the external manifestation(s)—the symptoms—of the malfunction.

Once the symptoms have been described, the trouble shooter performs Step 2 of the trouble shooting procedure. This step involves isolating the malfunction to the group of blocks which, if containing a fault, could produce the obtained symptom. This process is called "symptom to symptom area localization." It is made possible by the unvarying relationship between symptoms and the areas of the system which govern their production. Each signal channel of a radar system, and each functional stage within that channel, serves a particular purpose. When a malfunction occurs, a particular symptom will appear. This symptom might be specifically related to one trouble shooting block within a channel; at the very least, it can be related to a small number of blocks within a channel.

[1]See HumRRO Technical Report 63, *op. cit.*, for complete description of the FORECAST trouble shooting procedure.

For the repairman to make use of this relationship, he must be aware of the general function of each signal channel and each block within that channel. To aid the repairman in obtaining this information, the system analysts must determine the relationship between faulty trouble shooting blocks and the resultant symptoms. Thus, the purpose of analyzing a system in terms of symptom information is to provide the repairman with information that allows him to logically deduce the area of the system (symptom area) in which the fault is located.

Symptom information might be employed in two general ways. One way would be to use this information to isolate the malfunction to one block, or even to one part within that block. Sometimes this is possible, but not often. Even when it is possible, it usually involves making very fine symptom discriminations which are difficult to teach. To circumvent this problem, the FORECAST procedure uses symptom information to isolate a trouble to a general area of the system. Trouble shooting block outputs are then used to isolate the trouble to a block. By using this procedure the repairman does not have to concern himself with the countless variations which symptoms may take. Instead, the important point is whether a symptom, regardless of its subtleties, can lead the repairman to the group of blocks containing the fault. For example, the complete absence of a range sweep is a different symptom from the absence of a range sweep toward the maximum range of the radar system. However, if the same channel of trouble shooting blocks is involved in each instance, then the two symptoms can be combined into the general symptom, "something is wrong with the range sweep." This is an easy symptom for the repairman to detect and will always lead him to a certain group of blocks. He can then use block outputs to isolate the fault to a single block.

Collection of Symptom Information

When obtaining symptom information, the analyst should distinguish between symptoms at the same location produced by different conditions: (1) symptoms produced by the complete absence of a block output as contrasted with those produced by a distorted block output, and (2) symptoms produced by a faulty part as contrasted with those produced by a misadjustment.

The first step is to determine what symptoms are produced by the complete absence of a block output. To do this, the analyst examines each block, assumes the output to be missing, and predicts the result which will show up on the external indicator(s) associated with that block. The analyst should be certain to indicate all the places where the symptoms might appear. Usually, the same symptom may be produced by any one of a number of blocks within the same channel.

In some cases the relationship between symptoms and block outputs cannot be determined by analysis of schematic diagrams and handbooks on theory of operation. In such cases the analyst must go to the system, destroy the output of each block in turn by pulling a tube, disconnecting a cable, or removing a part, and record the resulting symptoms.

In some instances the analyst must determine whether a faulty part within a block will destroy the block output completely or only distort that output. If the output is only distorted, then he must identify the resulting symptom. Finally, the analyst must decide whether this symptom is different enough from that produced by the absence of a block output so that both symptoms should be specifically taught to the repairman. Such decisions are difficult to make, but fortunately the occasion for making them does not arise often.

Obviously, a bad tube will usually cause the complete absence of block output. Many of the parts within that block, if faulty, will also result in absence of output. Thus, symptoms produced by bad tubes, capacitors, resistors, and so forth, are usually the same or so similar that they can be described in similar terms. When this is not so, it is best to describe the particular symptom in question, then relate it to the one or more blocks that may contain the fault.

So far, the discussion has dealt with symptoms produced by faulty parts. It is necessary also to determine those symptoms produced by faulty adjustments. Certain symptoms can be directly associated with adjustment problems. The analyst can derive these by determining, either theoretically or on the equipment, what happens when adjustments are misadjusted first in one direction and then in the other. There is another group of symptoms which may be due either to a misadjustment or to a faulty part. These can be handled by first determining what symptom will occur when there is a misadjustment. If the symptom is similar to that produced by a faulty part, then that symptom is not included among the adjustment symptoms. In other words, the category of adjustment symptoms includes those symptoms that are produced only by misadjustments.

The rationale for the FORECAST treatment of adjustment problems is as follows. Certain misadjustments produce symptoms that are similar to those produced by faulty parts. When such symptoms occur, the repairman can not know immediately that an adjustment is at fault. Therefore, he must interpret the symptom in terms of which trouble shooting blocks may contain the fault. He can then check the block outputs of these suspected blocks until the faulty block is found. If this block contains an adjustment, he can check to see if the trouble is due to a misadjustment before checking the individual parts within the block.

One important restriction should be placed upon this procedure. Assuming that everything once was properly adjusted, the presence of a symptom indicates that some part is out of tolerance. The symptom is seldom the fault of adjustments, which cannot readily be changed. Quite possibly one or more adjustments can now be reset, and thus, for a time, the effect of the faulty part is overcome. Eventually, however, the faulty part must be replaced, and when this is done the system must be readjusted. Therefore, the approach stresses that adjustments should not be moved indiscriminately.

In the FORECAST approach, the repairman is taught to trouble shoot to a block and then is told that he may first check certain

adjustments that are contained within the block. However, the system analysts must determine whether these adjustments affect the output of any preceding blocks in the same channel. If they do, then the repairman should be instructed to trouble shoot for a bad part and leave the adjustment(s) alone. By doing this, chances of misaligning an entire channel of the system are reduced.

At this stage of the analysis, the analyst should have before him a list of all the trouble shooting blocks in the system and, for each block, a description of the symptoms which should be produced if the block contains a malfunction. The next step is to collate this information in terms of blocks which produce similar symptoms. The result of this will be a set of statements such as:

(1) Symptom: Electronic cross missing on PPI and PI scopes— malfunction can be in Block C, D, E, or F.
(2) Symptom: Cannot track targets in automatic mode— malfunction can be in Block H, I, or J.
(3) Symptom: High voltage meter reads high in current and low in voltage—malfunction in Block M, N, or P.
(4) Symptom: Range sweep jumps across A-scope as range hand wheel is turned—adjustment A is misadjusted.

The above information is then grouped by type of symptoms, for easier presentation to the students. Grouping into four types of symptoms is useful for training purposes: (1) Meter symptoms, (2) scope symptoms, (3) operational symptoms, and (4) adjustment symptoms. The information is then used in devising conference and practical exercise material for training in symptom interpretation.

REQUIRED CHECK POINT INFORMATION

Once a system has been analyzed into trouble shooting blocks, the analyst can begin to specifically determine what the wave form and voltage readings should be at each of the block output check points. This is a two-stage process in which the initial information is obtained by theoretical analysis of the system, using schematic diagrams and manuals on theory of operation. These sources will not provide all the desired check point information, so the system itself must be studied to determine those block outputs which can not be readily predicted by schematic analysis. The desired check point information consists of the following:

(1) The location of the check point.
(2) The normal reading at the check point.
(3) The testing instrument to be used at the check point.
(4) The conditions under which the check point reading should be taken. These include:
(a) The mode of operation of the system.
(b) The special testing accessories, if any, that are required.
(c) The tubes that should be pulled or cables and/or wires that should be disconnected before making the check.

Use of Check Point Information

In the discussion of symptoms the first two steps of the FORECAST trouble shooting procedure were described. These steps involved the operational checkout of the system to collect symptom information, and the interpretation of this symptom information in terms of which blocks might contain the fault. In some instances it is possible to isolate a malfunction to one block on the basis of symptom information, but this is not generally the case. Usually, symptoms are used to narrow the trouble to a small group of blocks. Block outputs—wave forms, voltage readings, or meter readings—are then used to isolate the trouble to one block.

In radar systems there are usually a few check points that, because of their proximity to high voltages or their inaccessibility, cannot be safely or easily checked. Blocks associated with these points can best be checked by chassis substitution.

Check Point Location

During the blocking portion of the analysis, the location of each check point is tentatively established. These locations are determined on the basis of schematic analysis, and theoretically are the best check points for checking out the blocks. However, at this stage of the analysis little is known about the accessibility of these check points. It can be assumed that built-in check points and check points at cable ends are usable on site, but those located at tube pins may not be. If photographs are available, they may provide some information on this score. Eventually, however, the equipment itself must be checked to ascertain that all points can be used by repairmen at the site.

Inevitably, some check points will not be accessible and new ones will have to be selected. This should be done while working at the equipment. The general procedure is to re-examine the block whose outputs are not accessible, select a new check point and/or reblock that portion of the system, then check to see that the new check point is usable on site.

Testing Equipment

To use trouble shooting blocks most efficiently, the repairman should know what the normal reading should be at each block output and should have some means of checking, on site, the critical aspects of these outputs. These ideal conditions are seldom met. Usually, the analyst must determine what testing equipments will be available and what the potentialities of those equipments are. He must then attempt to specify the characteristics of check point outputs in such a way that they can be checked with on-site equipment.

Most complex electronic systems have one or more built-in multimeters and oscilloscopes which can be used for testing purposes. The system should be blocked so that maximum use can be made of these built-in testing devices. When a choice exists between the use of equally

valid multimeter or oscilloscope measurements, the multimeter should be used, because it is usually more readily portable and is easier to set up.

The use of refined but bulky on-site test equipment requires some comment. In general, use of such equipment should be avoided but there may be instances when it should be employed. For example, a block may appear to have a good output when measured by a multimeter or by an oscilloscope, but the frequency of the signal may be incorrect. If this is the most critical aspect of the output, then it should be measured during trouble shooting even though the measurement is time-consuming because of the testing equipment involved.

Normal Readings at Check Points

In practice, collecting block-output information is often a difficult process, especially for a system that has not yet reached the field. The system analyst needs the following information:

      (1) What the normal reading at a check point should be, includ-
           ing all critical aspects of the reading such as amplitude,
           rise time, and/or duration of signal.
      (2) What the tolerances of the output signal should be.

This information is collated and presented in handout form to the student repairman.

During the blocking portion of the analysis, the nature of the block output(s) is usually determined in cursory form. The schematic diagrams and theory of operation should again be consulted to see whether a refined description of the output can be made. When these descriptions can not be made on the basis of printed material, as often happens, the nature of the output must be determined by checking the system.

In the immediately preceding section, the relation of testing equipment to block outputs was discussed. It should again be emphasized that test equipment must be considered when describing block outputs. It is of no use to describe a wave form as having a rise time of 2 microseconds if this can not be observed on the test equipment. In reality, we are dealing here with the distinction between theoretical and obtained measurements. A block output, particularly a wave form, can be drawn on the basis of theoretical information. On sensitive Ord-6 or Type-IV equipment, the obtained wave form might approach this theoretical shape. However, with on-site test equipment the wave form may look quite different, solely because of the insensitivity and/or the settings of the equipment. Thus, the on-site repairman should know how the block output will look with on-site test equipment and should also know the various settings his test equipment should have in order to observe the proper on-site reading.

The tolerances of an output signal are especially difficult to determine. Probably the manufacturer is the best source of this information. Unfortunately, this information is usually not included in early publications for maintenance of the system, but some estimate can be obtained from analysis of schematic diagrams.

Testing Conditions

To measure a block output, certain things may have to be done to the equipment and/or special testing accessories may be required. The analyst must determine this so that the information can be passed on to the repairman.

Figure 17 contains the instructions given to FORECAST-trained M-33 repairmen for preparing the M-33 IFC system for checking purposes. All these instructions were designed to ensure that the system would be operating in the same manner as when the normal block outputs were obtained by the analysts. In addition, special instructions are sometimes needed for particular checks. For example, the transmitter may have to be firing, certain switches be depressed, and so forth. All this should be specified when appropriate.

Instructions for Making Check Point Measurements

BLOCK CHECK POINTS

When taking Check Point readings the following should be observed:

1. Set Test Amplifier Gain at maximum.

2. Set Test Amplifier Attenuator as specified on Check Point sheet.

3. Set Range Dial at 50,000 yards.

4. Set IF Attenuator at 15 unless otherwise specified.

5. Set TS-352 at 20,000 Ohms per volt scale, when measuring DC voltage.

6. Set TS-352 at 10,000 Ohms per volt scale, when measuring AC voltage.

NOTE: Wave forms and meter readings may vary slightly from those pictured or listed.

NOTE: Schematic numbers and tube numbers are associated with the underlined block.

Figure 17

Often special testing equipment must be used to check out a block. Usually this involves the use of a tube adapter or a terminating resistor. This should be determined by the analyst.

Finally, to check out a block, tubes and cables may have to be disconnected. Unsoldering a wire may even be required. These requirements must be determined and specified by the analyst.

Example From FORECAST M-33 IFC Check Point Sheets: Tracking Subsystem

SCHEMATIC NUMBER	BLOCK	TUBE NUMBERS	CHECK POINT	WO/EXP SWEEP	WAVE FORMS and METER READINGS	W/EXP SWEEP
1	Pulse Synchronizer to Transmitter Pulse Pre-Knock	V1 & V2	V2, Pin 2 Pulse Synch		Test Amp Atten Set at 50	
2A	Transmitter Pulse to Trigger Generator	V5	J4 (P35) Trans Pulse J1 (P1) Trigger Gen Track H.V. Meter (Mag must be ON)		Test Amp Atten Set at 10 P.S. cur. - 45 Mag cur. - 6 P.S. volt. - 8	
3	Trigger Generator to Modulator	V1 & V2	J2 Trigger Gen J1 (P1) Modulator Track H.V. Meter (Mag must be ON)		Test Amp Atten Set at 50 P.S. cur. - 45 Mag cur. - 6 P.S. volt. - 8	
4	Modulator to Magnetron	V1, V2, V3	Reverse Cur. Meter Track H.V. Meter (Mag must be ON)		Reverse Current Meter - 6 P.S. cur. - 45 Mag cur. - 6 P.S. volt. - 8	
6	Magnetron to Duplexer	V2 & V3	Reverse Cur. Meter Track H.V. Meter (Mag must be ON)		Reverse Current Meter - 6 P.S. cur. - 45 Mag cur. - 6 P.S. volt. - 8	
7A	Duplexer	TR V6 ATR V4, V5	Wave Guide (Mag must be ON)		No arching in Wave Guide	

(Continued)

Figure 18

Block Check Point Sheets

There are often hundreds of check points for one system and for each check point there may be a dozen items of information which the repairman should have when making a check at that point. Obviously, the repairman cannot remember all this information. This problem can be handled by putting all check point information in handout form such as that shown in Figure 18. In column 1 is listed the page number of the schematic TM in which the schematic diagram of the block being checked can be found. In column 2 the block being checked is listed with the block(s) to which its signal goes listed below it. Column 3 lists the tube numbers and column 4 the block check point, including the chassis on which the check point is located. If the check point is at a meter, then the name of the meter is listed. Notice that the required operational state of the system is noted in parentheses—for example, "Mag must be ON." Column 5 contains all pertinent information regarding the expected reading at the check point. This information includes (1) the normal appearance of the oscilloscope or voltmeter, (2) any special setting information for the test equipment, and (3) normal variations, if any, in the meter readings.

FORECAST MOCK-UPS

INTRODUCTION

For electronics training programs, the use of certain equipment is often required. In many cases the equipment that the student is learning to maintain is available in sufficient quantity so that most of his training can be given using that equipment. When real equipment is not available, when it is very costly, or when there would be danger in allowing novice repairmen to work on it, some type of simulator must be devised for training purposes. In addition, greater proficiency might result if mock-ups were used for certain portions of the training, even when the actual equipment is available.

In the process of implementing the concepts embodied in the FORECAST method of systems analysis, two types of mock-ups were designed and constructed. The "operating mock-up" was designed to teach operating and energizing procedures, and the "maintenance mock-up" was designed to teach the trouble shooting procedures applicable to the particular system being studied.

In this section the design of the FORECAST mock-ups is described, and the rationale underlying the design is discussed. Evidence regarding the efficacy of the training mock-ups of the M-33 IFC system is presented. Difficulties likely to be encountered while constructing a mock-up are discussed, along with considerations regarding degree of system simulation, information required for mock-up construction, the obtaining of information for mock-up construction, and the desirability of advance planning for the early production of mock-ups of equipment. The section ends with a summary of the activities that must be undertaken to design and construct a maintenance training mock-up based on FORECAST principles.

FORECAST OPERATING AND ENERGIZING MOCK-UPS

Description

One of the earliest uses of the FORECAST concepts was in the construction of a mock-up for simulating the operation of the M-33 IFC system. This mock-up simulated the operating controls of the Acquisition and Tracking Radars, and the power panel to energize them. Since

the research was directed toward problems in electronics maintenance training, it was necessary that repairmen be adept at operating and energizing the system. The techniques of cue-response analysis were applied to the energizing and operating routines of the M-33. The results of this analysis were used to design the mock-ups.

The M-33 energizing mock-up consisted of two desk-top consoles (see Figure 19, at right), with a patch panel at the back. The consoles contained switches, meters, lights and other controls arranged spatially to correspond to the M-33 energizing panel. The patch panel was used by the instructor to connect the controls on the consoles to the mock-up power supply. By operating controls on the console, a student could evoke simulated system responses from the mock-up and in this way could learn the energizing routine.

The operating portion of the mock-up consisted of large sheets of plywood mounted with switches, lamps, and dials, all oriented properly to simulate the tracking control console and the tactical control console (see Figure 19, at left; only the tracking control console is shown). The switches were electrically interconnected so that actions at one place would result in responses at another place. The M-33 A-scopes and PPI scope were simulated by holes cut in the plywood. A transparent plastic plate covered the holes, and cards marked appropriately to simulate the actual displays were placed behind the holes. In this way the students saw through the holes a representation of the scope faces. The cards could be interchanged by the instructor. By using these "scopes" and by operating the controls on the operating and energizing mock-ups, it was possible for the student to run through the entire battery-engagement routine.

Mock-Up Effectiveness

To test the effectiveness of the operating and energizing mock-ups, they were used to train a group of high school students in the M-33 energizing and operating routines. These students were then taken to an actual M-33 site and permitted to energize and operate live equipment. They were able to do so to the extent that they actually tracked targets after only a very short period of live-equipment practice.

The mock-ups were not used to train students in the procedures for circumventing enemy electronic countermeasures, in the daily maintenance tasks, or in judgmental skills like setting gain and intensity at proper levels.

Mock-ups are used to teach some of the over-all task. If this can be done before going to the equipment, then equipment time can be more effectively used. It is a matter of division of labor. Thus, the following can be learned on the type of operating mock-up just described:

      (1) Order of carrying out certain operations.
      (2) Location of controls.
      (3) Purpose of controls.
      (4) Role of each operator in the operating team.

FORECAST I Operating and Energizing Mock-Ups
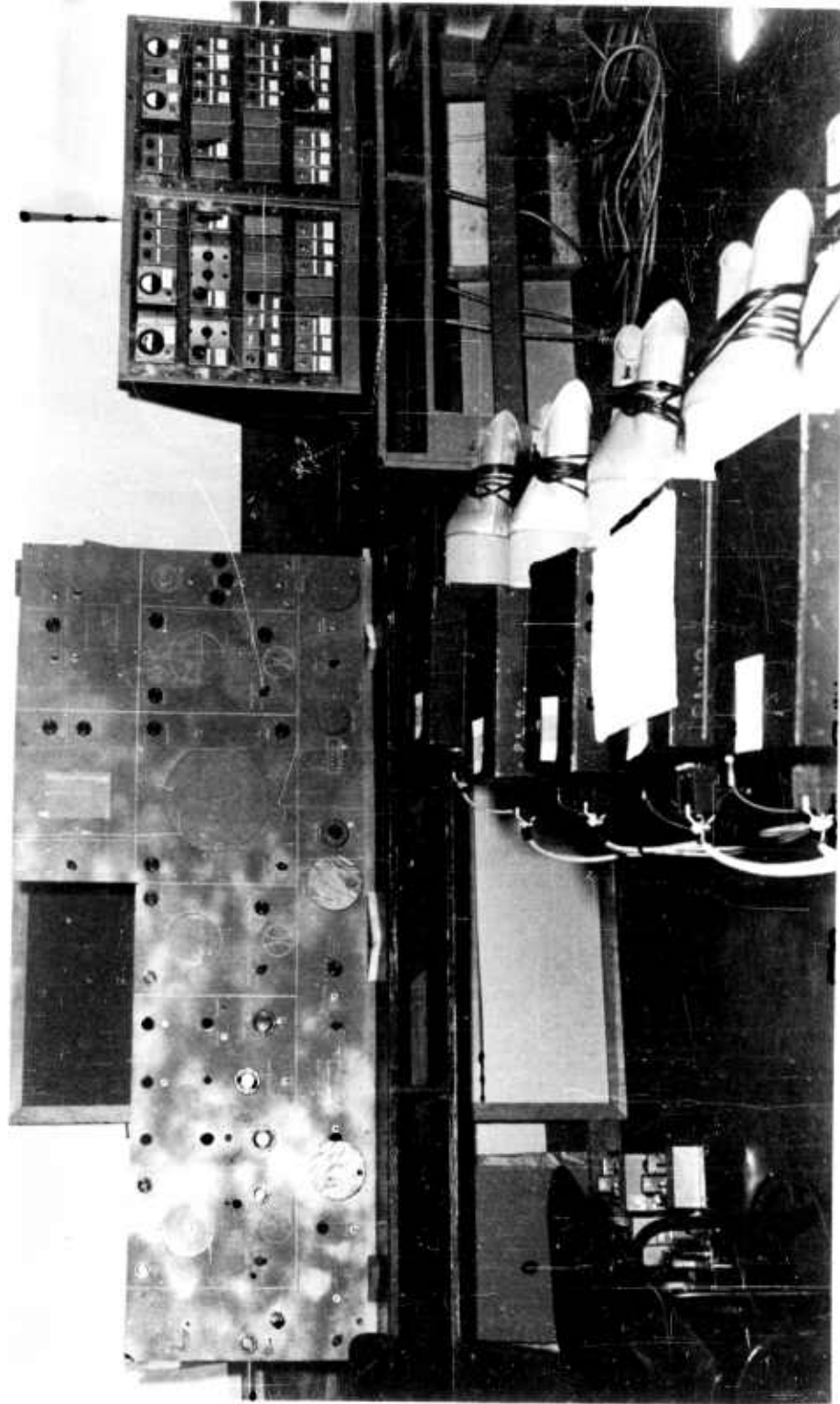
Figure 19

FORECAST MAINTENANCE MOCK-UP

Description

In addition to knowing how to energize and operate the equipment he is to maintain, a maintenance man must know how to interpret symptom and check point information to isolate a fault to a small group of parts. The FORECAST operating and maintenance mock-ups can be used to teach the operating procedures used for gathering symptom information (see Figure 20, depicting the FORECAST classroom). To teach the repairman how to use this information, a maintenance mock-up was developed.

The trouble shooting block diagram, one of the end products of the FORECAST method of analysis, was described in Section 1. In the M-33 studies, the tracking subsystem, for example, was analyzed into approximately 100 blocks. These trouble shooting blocks had one common characteristic—if all signals entering the block were good and any signal leaving the block was bad, then the trouble lay in that block. The maintenance mock-up was designed to simulate this block characteristic (see Figure 21).

This mock-up could be considered an activated, three-dimensional block diagram since it consisted of a series of boxes, each of which represented one of the blocks shown on the FORECAST trouble shooting block diagram (see Figure B-1 in Appendix B). Each of the boxes was labeled with the name of the block it represented, and two test points were mounted on the box. One of these test points was used if the signal to be measured at that block was a wave form; the other test point was used if the block output was a voltage. All boxes were connected to a control panel (Figure 22). By manipulating a switch on the control panel corresponding to each box, an instructor could make it appear as if malfunctions were in the box (actually, the box contained only a relay, a switch, and a few wires). That is, the instructor could make a good or a bad wave form or voltage appear at the box check point, for each box of the mock-up.

To simulate malfunctions realistically on the mock-up, the system analyst must determine for each malfunctioning block what other blocks should have incorrect outputs. That is, when a malfunction occurs in live equipment it may affect the output of many subsequent stages. Thus, when the fault is located in a particular trouble shooting block, certain other blocks will also have bad outputs. This pattern of incorrect outputs can be determined by analysis of schematic and block diagrams, or malfunctions can be introduced into live equipment and the outputs of blocks in the same and/or associated channels checked for correctness. When the resulting information is collated, a set of mock-up malfunctions can be derived that lists, for a malfunction in a particular block, the other blocks whose output should also be made incorrect by the instructor.

Five devices called "wave formers" simulated the test oscilloscope of the M-33 and displayed wave forms corresponding to each check point. The wave formers were simply boxes containing a set of plexiglas plates

Classroom Arrangement of Operating, Energizing, and Maintenance Mock-Ups
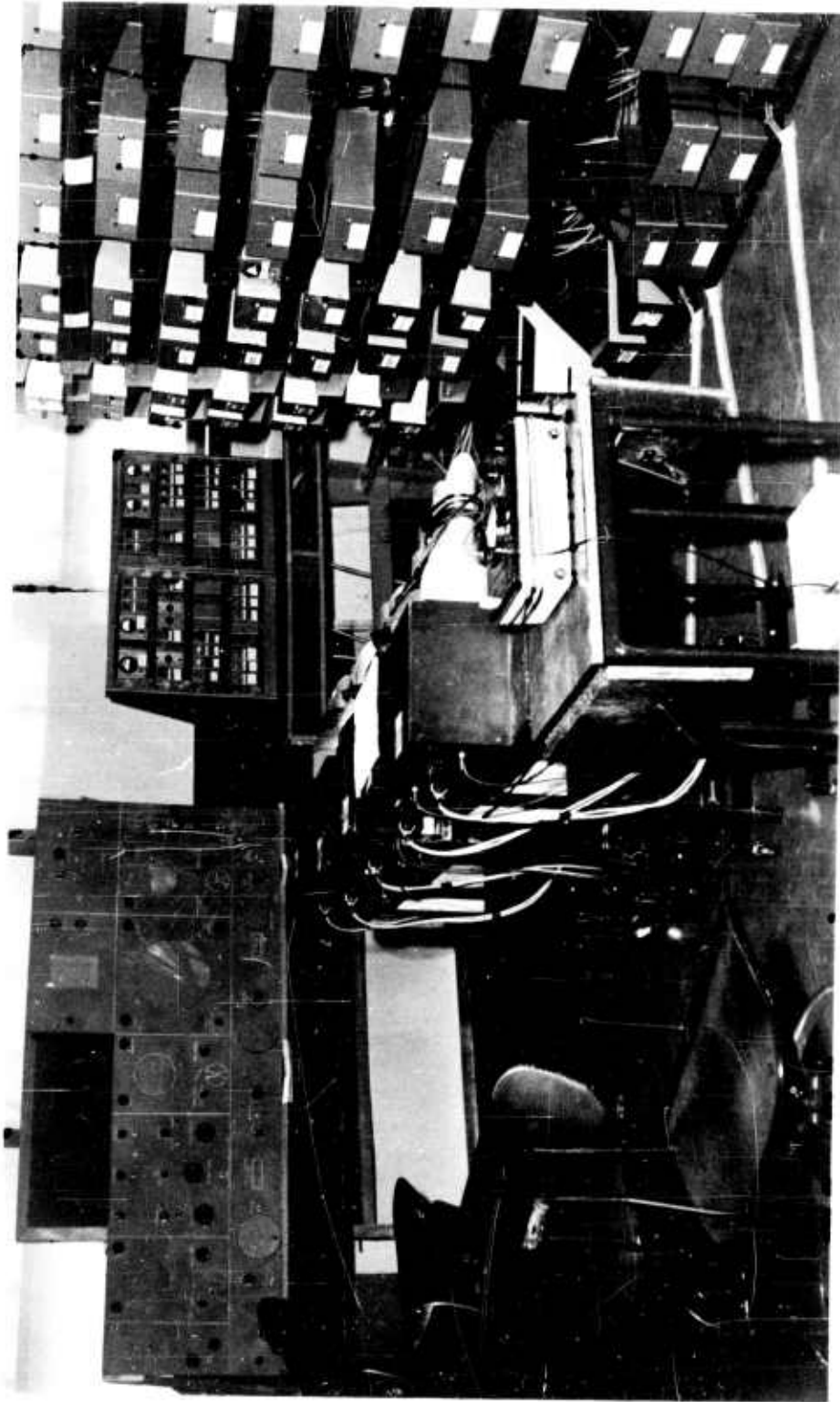
Figure 20

FORECAST Maintenance Mock-Up—Front View

Figure 21

65

FORECAST Instructor Control Panel and Patch Panels
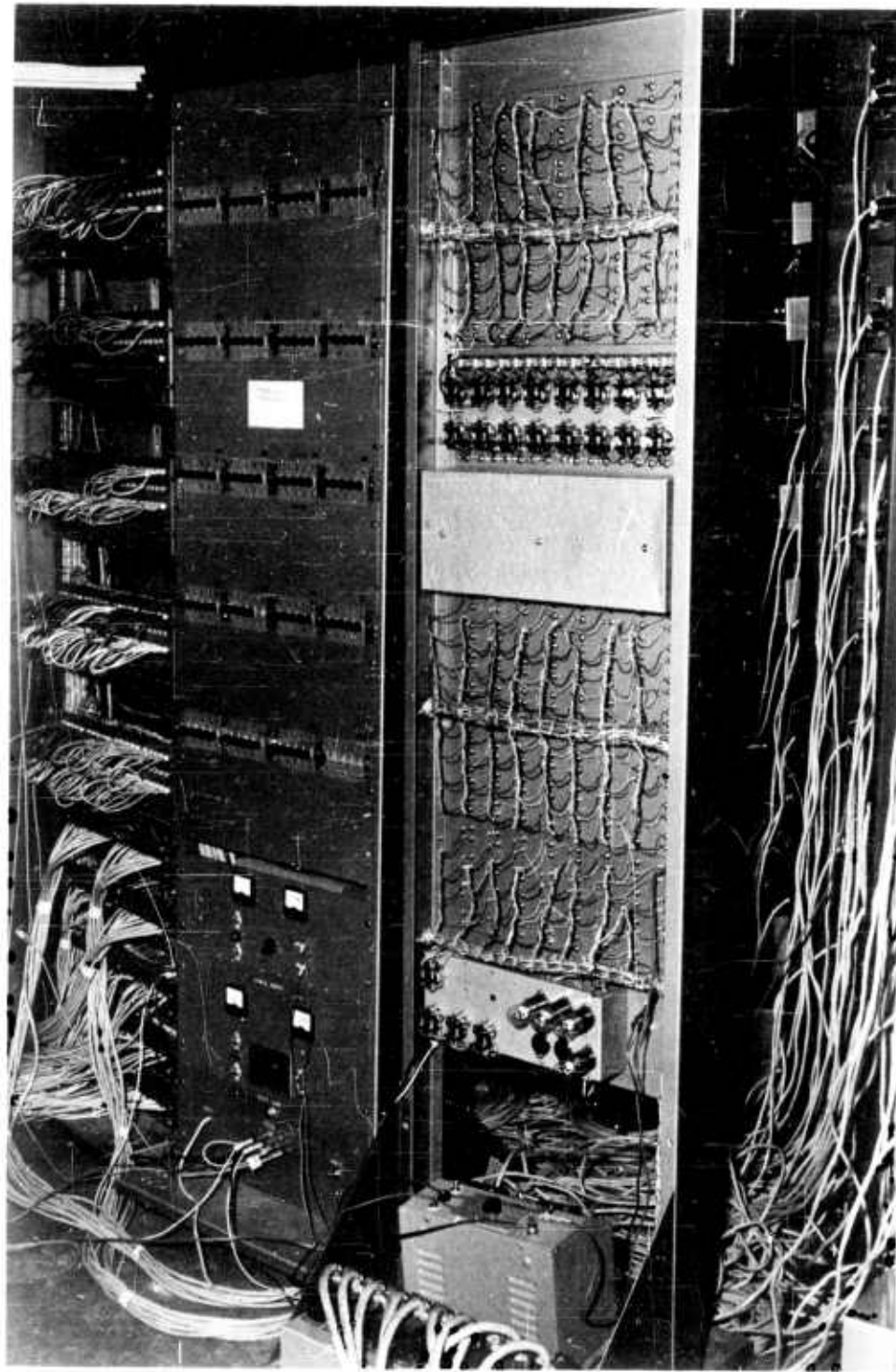
Figure 22

that were etched with appropriate wave forms. When a test point was touched, lights would illuminate a corresponding plexiglas plate. The etched wave form on the plate would become visible through the viewing port. Each trouble shooting block had two plexiglas plates associated with it, one inscribed with a good wave form, the other inscribed with a bad wave form. Each wave former contained 20 plates—ten good, ten bad. This simple mechanical arrangement was an economical and effective means for displaying wave forms.

Description of Voltage Simulation

Some mock-up check points were designated as voltage check points. A voltmeter was used to measure the voltage appearing at these points in the real system. In the mock-up, two potentiometers were connected to each voltage check point through the contacts of a relay. When the relay was inert, one potentiometer was connected to the check point. When the relay was activated, the other potentiometer was connected. One potentiometer was adjusted for a check point voltage proportional to the actual value measured on real equipment. The other was adjusted to a plausibly incorrect voltage resulting from a malfunction. To simulate the malfunction, the relay was activated (by flipping a switch on the control console) and the bad voltage applied to the check point. Otherwise the relay was inert.

The maximum voltage available at the test point was 12 volts DC. To produce readings of 50 volts, for example, it was possible to use a 15-volt instrument range, redesignated as 150 volts. The potentiometer would be adjusted to produce a 50-volt reading on the 150-volt scale, even though the 15-volt range was actually used. In this way, the student used the correct scale and what he believed to be the correct range in making his checks for any particular voltage check point.

More complicated techniques could have been used for generating wave forms. Oscilloscopic photoformers are available for wave form simulation. While there is no question that such photoformers could have been employed, there is doubt that the possible increase in training value would justify the additional expense associated with their use. Photoformers probably are required for certain types of training. For example, if the problem is to train men to associate various features of bad wave forms with the parts which effect those particular features, then photoformers should be used. This is because the training problem in such a situation involves learning to make fine discriminations. In the FORECAST type of analysis, the repairman interprets wave forms in terms of good or bad blocks. This is a grosser type of discrimination, and learning to do this does not require high-fidelity simulation.

Mock-Up Effectiveness: The Mock-Up Study

During the summer of 1959, a series of pilot studies was undertaken at the Aberdeen Proving Ground under the sponsorship of the Ordnance Training Command. Among these studies was one designed to test the effectiveness of the maintenance mock-up as a training

device. The results and the design of this study are discussed in the Research Memorandum, "Increasing Electronics Maintenance Proficiency Through Cue-Response Analysis."[1] Essentially, students trained primarily on the FORECAST M-33 Maintenance Mock-up were tested for their trouble shooting proficiency on real equipment. The results of that study were compared with results obtained from a similar group trained wholly on real equipment. The comparison showed that students trained with the mock-up performed significantly better than students trained on equipment alone.

There is some reason to believe that the higher trouble shooting proficiency in the mock-up group was due largely to the increased amount of trouble shooting experience that a student can obtain if the training includes using a mock-up. Students trained with a mock-up did not have to spend time opening up equipment, operating interlock switches, setting up and adjusting test equipment, pulling out chassis, and a dozen or so other simple, yet time-consuming activities intimately related with trouble shooting real equipment. Therefore, students trouble shooting the mock-up were able to spend more time making the decisions and interpretations that form the basis of the trouble shooting activity.

Probably the most difficult task of the trouble shooter is the interpretation of symptom and check point information. Training on the maintenance mock-up emphasized this activity and stressed the best procedures for obtaining this information. Thus, by using a mock-up students can receive more experience at interpreting cues in terms of where in the system the trouble might be.

It should be clear that using a mock-up is not advocated for all segments of the trouble shooter's training. The real equipment is the best place for teaching certain of the required procedural and manipulative skills (as well as for learning fine discriminations). However, the learning of these skills seems to interfere with the learning of the cognitive aspects of trouble shooting, and therefore it is advocated that the cognitive aspects be taught on a mock-up.

Degree of Simulation

The term "degree of simulation" is used to indicate how closely the mock-up resembles the real equipment. Naturally, it is possible to use the real equipment itself in training, and for some purposes this may be the only feasible solution. While this could be called perfect simulation, it has been observed that perfect simulation is not necessarily a desirable end. As was learned in the M-33 Mock-up pilot study, the system itself is not a particularly good training vehicle during the early stages of training. How closely, then, should a mock-up resemble the real equipment? This depends upon the training objectives to be met and the risk involved in allowing an incompletely trained man to complete his training on real equipment.

[1]Edgar L. Shriver, C. Dennis Fink, and Robert C. Trexler, *Increasing Electronics Maintenance Proficiency Through Cue-Response Analysis*, Training Methods Division, HumRRO, October 1959.

With respect to the design of trouble-shooting mock-ups incorporating the principles of the **FORECAST** method of system analysis, there are several criteria for determining the proper degree of simulation. These are:

(1) Physical location face validity
(2) Activated check points
(3) Check point data validity
(4) Symptom validity

Physical Location Face Validity. One of the knowledges which must be learned by any repairman is the location of parts within the system he is to repair. In the M-33 studies, there were actual M-33 systems available for teaching students where to find various malfunctioning chassis; the mock-up was not designed to teach location. When there is a training objective of teaching location, and real equipment is not available, physical location face validity that is at least "skin-deep" must be built into the mock-up. That is, the relative spatial position of scopes and other check points and symptom indicators on the mock-up should be similar to their positions on the real equipment.

In this connection, the scale of the mock-up deserves some comment. The actual equipment itself may very likely determine what scale the mock-up should have. It is conceivable that 1:1 may be undesirable not only from a training standpoint, but also from a support standpoint. That is, a system may be so large that it would be difficult to house a full-scale mock-up of it; in such a case, the relative size of the mock-up could be reduced without much loss in training effectiveness. On the other hand, a system may be so small that it would be difficult to work on a life-sized mock-up, and enlarging the scale of the mock-up might therefore be justified.

Activated Check Points. The FORECAST method of system analysis is used to create trouble shooting blocks for which there is at least one check point per block. It is necessary also to determine what information normally appears at each of these check points—a voltage, a wave form, or a meter reading. This information is obtained by consulting system experts or the equipment itself. These data are then tabulated in the form of check point sheets, and are made available to the repairman and to the student (see Figure 18). During his training the student uses these check point sheets while trouble shooting the mock-up. For any particular problem, he makes measurements at selected mock-up check points and compares the obtained information with that listed on his check point sheet. To accomplish this training, it is necessary that the mock-up check points be activated so that either a good or a bad signal can be made to appear at any particular check point.

Check Point Data Validity. The validity of the check point data is a matter of some concern. With little or no thought one might be tempted to demand that the check point data be 100 per cent accurate—that errors in check point data will be intolerable. But what meaning has such a demand? Any measurement a repairman makes is subject to many sources of error: reading error and instrument error, to mention two. Even if it were possible to measure the exact values appearing at check

points, of what use would they be, since it is well known that these values will be different across several systems and will fluctuate within certain allowable limits even within a particular system? It is economically unfeasible to make the same measurement a great many times in order to obtain average values for the check point data by statistical means. Since that is true, how much less economical is it to perform these same measurements on every system to be produced? Clearly, the proposal is fantastic.

One cannot speak of accuracy without speaking at the same time of limits. The limits, in turn, must be consistent with the training objectives. It is a fact that students, at any given stage of their training, are capable of making discriminations with only a limited degree of accuracy. They cannot make finer discriminations, even though the physical basis for finer discriminations is present.

The training objectives of the FORECAST-type mock-up are therefore to present the critical aspects of normal live equipment outputs as check point data. Fine discriminations are not generally needed for recognition of the presence or absence of these aspects. For example, assume that at a given check point the wave form is supposed to be a pulse. The critical aspect of this pulse is the interval of time between the system trigger and the instant when the pulse reaches a certain height. It is quite possible that the top of the pulse or the trailing edge of the pulse will have no effect whatsoever upon the system; therefore, whether the pulse is ideal or only approaches ideal is really incidental. In fact, the trailing edge of the pulse may even decay in oscillations. So long as the pulse occurs at the proper time, it is a good signal. This check point wave form could be obtained from real equipment or from system experts. In this case it is conceivable that, from system to system, the wave form would differ quite markedly. Yet in every system which is operating correctly these wave forms would be good, since the critical aspect of the wave form is the time interval.

Still another example would be the wave form that consists of a definite number of oscillations. It may be 51 cycles of a sine wave. The harmonic content (within limits) of the sine wave may be only incidental, since the sine wave will be clipped, differentiated, and turned into 51 pips. All that is really necessary is that there be 51 oscillations looking somewhat like sine waves. The critical aspect of this wave form is the number of oscillations in the given length of time.

Symptom Validity. Symptoms are the external indications of a malfunction somewhere in the system. When a part goes bad in a real system, it produces certain changes in the behavior of the system that can be recognized as indicating an out-of-tolerance condition. When this happens, the repairman energizes the equipment, makes various measurements, and operates certain controls to detect the deviation from what he knows to be correct operation. The routines which the repairman runs through in this process are called "symptom gathering" or "operational checkout." On the basis of his symptom-gathering procedures he forms a preliminary hypothesis, and on this basis he performs additional checks designed to test his hypothesis.

The trouble shooting mock-up must be congruent with the real system with respect to symptoms. While it seems desirable, it is by no means necessary that the mock-up display symptoms in the same way that the real equipment displays them. A compromise can be struck between fully automatic symptom display and no symptom display at all. Clearly, symptoms must be displayed. The question is how to do it.

One way is to permit an instructor to "talk" the student through the symptom-gathering stage. This technique has several advantages to recommend it. A skillful and knowledgeable instructor can guide the student so that he will learn to ask the right questions. In other words, the student will learn an efficient symptom-gathering procedure. Contrast this result with what happens if the student were simply abandoned to develop his own symptom-gathering procedures, whether on a "fully automatic symptom display mock-up" or on a real system. Even taking into account the highly motivating character of a trouble shooting mock-up, it is quite likely that the average student would soon become discouraged by his failure to make any quick progress without instruction.

Obviously, the solution is not clear-cut. The mock-up can be used to present certain displays and the instructor can present others. Determining the relative proportion of each type of presentation will depend upon many factors, not the least of which is cost. From the standpoint of embodying the FORECAST principles into the design of the mock-up, it is relatively unimportant how much of the symptom information is automated and how much is manually presented. What is important, however, is that the symptom information must reflect real system behavior adequately for training purposes. Thus, when the student repairman runs through the symptom-gathering procedures, or the operational checkout, he should obtain realistic representations of the condition of external indicators. By gathering bona fide symptom information on the mock-up, the student becomes familiar with the nature of typical symptom patterns.

It is essential that accurate symptom information be obtained. When the pip-gate generator goes bad in an operating M-33, it causes other parts in the system to have bad outputs too. It is not enough, therefore, simply to make the output of the pip-gate generator bad on the mock-up. All blocks that would be affected by a bad pip-gate generator in a real system must also be affected in the mock-up. This one-to-one correspondence between the real system and the mock-up with respect to trouble shooting malfunctions is of primary importance. When a block goes bad in the real system, detailed observations of the system must be made to gather all relevant symptoms. These are the symptoms that should be presented during mock-up training, so that the student can learn to interpret symptoms in terms of blocks which may contain a trouble.

MOCK-UP DESIGN AND CONSTRUCTION: OBTAINING INFORMATION

Objectives

The objectives of FORECAST research visualize a situation in which a training program can be developed, mock-ups built and used,

students trained and graduated, and repairmen assigned to the field by the time the first systems become available for use in the field. It is possible to achieve this goal only if access to adequate information is a possibility.

When a system becomes available to the field, usually all the information necessary for constructing a training program based on the FORECAST principles has become available and is relatively easily accessible. Unfortunately, this is far too late in the life span of the system to be satisfactory. Obviously, the requisite information must be obtained much earlier.

Nature of the Information

One characteristic of the development of new weapon systems seems to be that they are usually more sophisticated versions of earlier weapon systems. The Nike Ajax, for example, could be considered a more sophisticated M-33; the Nike Hercules, a more sophisticated Nike Ajax. Even before the first production model of a new system leaves the assembly line, the second generation is already on the drawing boards or in the prototype stage, and the third or fourth generation of this same system is being conceived. After a certain date, the design is frozen and any further modifications are made on second-generation designs. Unless this is done, there would be little chance of getting a large number of similarly designed systems into the field.

At the design freeze date, information of use to analysts in constructing the training course, including the mock-up, is available. It may be that some aspects of the new weapon system are identical with some aspects of the old weapon system. Other aspects of the new weapon system will be somewhat like those of the old system, whereas still others will be totally different. It should be possible, of course, to obtain, before the design freeze date, information relating to those parts of the system that remain the same. To be sure, some circuits will be changed even after the freeze date, and will appear as modifications to the produced systems. Mostly, however, the design of the system will be fixed at a certain time.

Before the freeze date, the theory of operation of the system, preliminary schematic circuit diagrams, and relatively gross descriptions of the physical configurations of the system become available. The theory of operation (not including a detailed description of the operation of each stage within the system) and schematic circuit diagrams constitute the bare minimum of sources of information with which to begin the analysis of the system using the FORECAST techniques. While these sources are not sufficiently complete in themselves, they provide enough information for making a first approximation. Using the sources, analysts can make a preliminary analysis of the system. Relatively quickly, however, questions will be raised for which the answers will not be available. Direct contact with knowledgeable engineering representatives of the manufacturer can expedite obtaining the required answers.

While the preliminary analysis of the system is being made, plans for the mock-up can be initiated by examining the available information

sources. As time proceeds, additional information is required both for the analysis and for mock-up construction.

The analysis of the system will result in a trouble shooting block diagram. Every trouble shooting block will have one or more output check points. Every check point thus identified will have associated with it the analyst's best estimate of the correct measurement at that point, with appropriate tolerances. Every trouble shooting block must be associated with the symptoms that would be produced if any of the parts within the block were to malfunction. The best estimates of these symptoms will be tabulated and will form the basis of the symptom lesson plans. From this preliminary analysis of the system, the number of trouble shooting blocks, the type of check point data, and the symptom patterns can be extracted for use in planning the capacity and flexibility of the mock-up.

At about this stage in the development of the training program, another level of information must be made available to the effort. This level of information includes revised, improved, or corrected theory of operation, the latest schematic circuit diagrams, and such additional information as may be available regarding the physical configuration of the equipment. As a result of this new information, revisions are made of the block diagram, check point locations and indicators, and symptom information.

To this point the analysis has proceeded primarily on the basis of information obtained from printed material. Ultimately, access to live prototype equipment will be necessary to ascertain the accessibility of check points and the validity of the predicted check point data, symptoms, and mechanical configuration.

Sources of Information

The manufacturer of the system is a prime source of information. He may, in turn, have other manufacturers under subcontract, and they will also be sources of information. Various organizations within the military service will possess information. These organizations, monitoring the contracts under which the weapon system is being developed, will have the authority to arrange for the information to be made available to the system analyzer at the right time.

Key Personnel Course. One of the routine techniques for transmission of information on new weapon systems from the manufacturer to the user is the key personnel course (KPC). Even though parts of a system may still be in the prototype or in the development stage, key personnel courses are conducted to provide selected personnel with information on the new system. The key personnel course conducted by the manufacturer of the system is often used as the basis for the Army's training course, since Army curriculum experts are frequently graduates of such key personnel courses. Since the KPC trains curriculum experts and becomes the basis of the Army's program of instruction, the resultant Army program is very largely structured by the manufacturer. As the manufacturer is necessarily oriented in terms of system engineering, the key personnel course also tends to be so oriented. As a result, the Army's final training course tends to be engineering oriented.

Drawings and Handbooks. "Yardstick" (approximate) dimensions of the mechanical features of the system are necessary for the construction of a mock-up which resembles the system. This information can be obtained long before the electronic details become final. Some dimensions can be obtained from a study of manuals available through the KPC, or preliminary handbooks. For particular consoles or chassis, the actual layout drawings are far too detailed for the purposes of mock-up construction. In addition, the mere size of any reasonably modern weapon system precludes the acquisition of detailed layout drawings for every chassis and console in the system. There would be literally thousands of drawings to go through.

Photographs and Prototype Equipment. Questions arise in the construction of a mock-up which can be answered adequately only by access to real equipment. For example, although the real equipment may have a chassis mounted in a console so that it will swing on a hinge to give access to some internal parts, the mock-up need not have a swinging chassis corresponding to this if all the test points for that chassis are located so that they can be checked without swinging open the chassis. If the photograph of the chassis in the KPC manual shows it opened or swung out, this does not provide enough information to answer the question; another photograph would be needed of the closed chassis.

Again, perhaps the photograph will show only the top side of a chassis, and the question is whether certain check points will be available through the bottom of the chassis, of which there is no photograph. Further, some chassis are totally enclosed. Whatever photographs of the equipment may be available at any particular time, they are certain to be limited in number. It is not possible to provide all conceivable pictures, and it has been observed that the pictures actually provided are generally not adequate. Therefore, access to real equipment is necessary, at least with respect to answering questions of the above type. There are, as will become clear, additional reasons for acquiring access to operating equipment.

Unenergized vs. Live Equipment. There are four types of information that must be considered when constructing a FORECAST-type mock-up. These are (1) yardstick dimensions, which include the external dimensions of the cabinets, type and placement of all external controls, and the location, dimensions, and form of mounting for all chassis; (2) check point location and accessibility, which includes the location of all check points and the determination that these points are accessible; (3) check point indications, which involve the determination of what the normal indications at each check point should be; (4) symptom information, which involves the determination of what symptoms will appear on external indicators as each trouble shooting block is made to malfunction.

All of the above information must eventually be checked on the equipment being analyzed. The first two types of information, yardstick dimensions and check point location and accessibility, can be checked on unenergized equipment. Arrangements could be made to obtain this information during the R&D evaluation of the equipment, as working with an unenergized system would not be apt to cause malfunctions.

To begin construction of the mock-up as soon as possible, yardstick, location, and accessibility data should be obtained as soon as

a prototype exists. Yardstick dimensions and check point location data are obviously required if the mock-up is to resemble the equipment; check point accessibility data is needed to assure that practical check points are selected. System analysts often discover, for example, that they cannot make a check where they thought they could because some part makes it mechanically impossible to place a test probe on the check point in question. Accessibility of check points can only be determined by examining hardware; the study of schematic circuit diagrams cannot provide this information.

During analysis, system experts make guesses with respect to the normal indications which should appear at each check point and the symptoms which should appear with incorrect output(s) of trouble shooting blocks. They predict also what type of test equipment is most appropriate for making checks at any particular point. These guesses must be validated on live equipment.

The validating of check point and symptom information can be particularly troublesome. Sometimes the system analysts cannot deduce what the check point for symptom information should be. In such cases the determination must be made wholly on live equipment. With respect to check point information, the critical aspects and tolerance limits for a particular measurement can be determined by systematically changing the value of the adjustments and/or some of the parts within the block being checked. This is a time-consuming process, and an attempt should first be made to determine whether design engineers can furnish the required information.

There are at least three ways in which symptom information can be validated. The output(s) of each trouble shooting block can be made incorrect by removing a tube; then the resulting symptoms can be noted. It is possible, also, to actually destroy a part in the live system and observe the effect. It could be argued that, with an obsolete system, this might be an acceptable procedure; with a new system, of which, perhaps, only one prototype exists, it may not be practicable to destroy parts. If this is the case, the best guesses of the system analysts, verified by design engineers, will have to suffice.

A requirement to provide the Army with maintenance training information is not new to manufacturers of weapon systems. What is perhaps new is that rather specific types of information are implied by the FORECAST method of system analysis. It makes sense that the types of information required for constructing a training program should be specified by training experts rather than by manufacturing experts whose principal interests lie in the design and sale of hardware.

Need for Coordination

The construction of a new weapon system is an extremely involved task, requiring coordination among many agencies. In Ordnance, for example, coordination must take place among the Army Rocket and Guided Missile Agency, the Ordnance Guided Missile School, the Ordnance Training Command, the Office of the Chief of Ordnance, and

such manufacturers as the Bell Telephone Laboratories and Western Electric, to mention a few.

Unless advance planning has provided for communication channels and authorized the expenditure of funds and use of equipment time, the appropriate information sources can provide adequate information to construct a usable training mock-up only, as it were, "on the cuff." Therefore, plans must be made and funding requested to obtain sufficient information to produce the mock-up in advance of the first scheduled training program for that system. This information is usually available at least a year before the date set for delivery of the first production system to the field. Sometimes attempts to obtain adequate information for the construction of a mock-up are met with resistance from those agencies best qualified to provide the information.

Information Validity

It might be reasoned that yardstick or check point data measurements on prototype live equipment are not meaningful, since there will be many changes. There are always many changes to a weapon system, even when the system has been in the field for years. Modifications are a fact of life, but, as a manufacturer is faced with a cutoff date on his design, so are the developers of mock-ups. It is possible that the mock-up will never look exactly like any particular on-site system. But, after all, it is highly unlikely that any one on-site system will be identical with all other on-site systems, since many systems will be in some state of modification at any given time. In order that this up-dating process may apply to the mock-up as well as to real equipment, organizational machinery must be set up to feed information on modifications to system analysts who will use it to modify the training program and the mock-up. It is expected, therefore, that a continual flow of information will be available to improve or up-date the mock-up as improvements are made in the real equipment.

SUMMARY

Characteristics of FORECAST Mock-Ups

Even when real equipment exists, mock-ups are useful training devices. They are virtually indispensable when real equipment does not exist, as in the early phases of system development. It is highly desirable to have trained repairmen in the field when the equipment reaches the field; using trouble shooting mock-ups increases the likelihood that training will be effective. The FORECAST mock-up has the following characteristics:

(1) It resembles the real system to the extent that consoles are oriented correctly to show location, that chassis are oriented properly within the consoles, and that check points are located correctly on the chassis.
(2) Check point data appear at check points.

(3) Means are provided for the display of symptoms, so that
the repairman can use exactly the same conceptual trouble
shooting techniques on the mock-up as he would use on the
real equipment.

(4) The mock-up is designed also to permit learning energiz-
ing routines.

Activities in the Design and Construction of Mock-Ups

To provide the mock-ups with the above characteristics, the follow-
ing activities must be undertaken:

(1) The system is analyzed in terms of trouble shooting blocks.

(2) Check points are identified—at least one per block.

(3) Predicted check point data are developed.

(4) Predicted symptoms are developed.

(5) A study of written materials, drawings, and the equipment
itself is undertaken to decide questions relating to mechani-
cal construction details of the mock-up.

(6) By examining real equipment, check point locations are
modified to ensure their accessibility.

(7) Predicted check point data are verified.

(8) As a result of activities 6 and 7, boundaries of some
blocks may be changed.

(9) Predicted symptom information is verified.

(10) The mock-up is constructed and set up to display authen-
ticated symptoms and produce corrected check point data
at the check points.

These activities are accomplished through the active coordination
and cooperation of all agencies possessing information, the system
analysts who are using the FORECAST method of system analysis, and
the consumer of the research product. Advance planning and fund
allocation must be accomplished for future systems to provide the
most rapid, effective, and efficient utilization of the FORECAST
research results.

APPENDICES

Appendix A

A DESCRIPTION OF ELECTRONIC WEAPON SYSTEMS[1]

This section provides a general description of electronic systems as they were viewed in the FORECAST research. The description will help the reader understand more clearly how the FORECAST method of systems analysis was developed. It is presented in the terms utilized in the study, in order to introduce the general approach taken in the maintenance task analysis—to describe and explain electronic weapon systems only at the level and in the detail required for an accurate definition of the repairman's job. Although the description uses cue-response terms, it can be reconciled with one using electronic terms.

Major electronic weapon systems such as the M-33 look, to the layman in electronics, like a mass of parts each of which seems to be related to every other. Of course, even the layman knows this is not the case, but it is difficult for him to see how the interrelations can be put in a meaningful pattern. To accomplish rapid trouble shooting, certain patterns of relationships and independencies must be utilized; a description of some which are employed in the FORECAST approach are as follows.

General relationships among components may be described in terms of signal flow. There are many relatively independent channels of signal flow in the M-33 system. A signal starts from some type of signal generator; then it goes through a series of electronic parts which constitute a "channel" for the flow. There are perhaps two dozen such channels in the Tracking Radar subsystem of the M-33. Each component in the channel changes the signal slightly; thus, the original signal is continually changed as it moves along its channel.

Most of the channels terminate on a portion of the equipment which makes the signal in them visible. They may end as a mark on a phosphorescent scope, or as a meter reading, or as a movement of an antenna. If a normal signal appears, all components in that channel are functioning properly. If a signal is abnormal, or if it fails to appear at all, a malfunction is indicated. Such indications are called "symptoms."

Before the terminal point of a channel is reached, signals may be switched from one channel to another by operator controls. An alternate channel may have a different terminal point than the original channel, or the alternate channel may lead back into the original channel before the terminal point. In some few instances, two channels may meet; then a new signal results, which travels in a new, third channel.

Visible signals appearing at the end of a channel on built-in indicators (equipment displays) are readily available to repairmen. Logically they are efficient isolators of malfunctions because they contain information that allows a distinction to be made between parts in various channels. For example, by merely looking at the M-33 track radar displays the

[1]This section is an excerpt from HumRRO Technical Report 63, titled *Determining Training Requirements for Electronic System Maintenance: Development and Test of a New Method of Skill and Knowledge Analysis*, by Edgar L. Shriver, June 1960 (Task FORECAST I).

knowledgeable trouble shooter can eliminate about 96 per cent[1] of the possible malfunctioning parts from consideration. This narrows the search to only 4 per cent of the parts because the abnormal signal is affected only by the parts in one channel and is independent of the parts in other channels. The trouble shooter has thus isolated the malfunction in general terms. The phrase used in the FORECAST approach for describing this process is "symptom to symptom area" identification.

Signals may be switched or sidetracked by means other than operator controls. Before the terminal point of the channel is reached, signals can be made visible by sidetracking them from their channels with portable test equipment (voltmeter, oscilloscope, ammeter). The appearance of a signal on these test instruments indicates whether all portions of the channel leading to this sidetrack are functioning properly. Indications from portable test equipment are called "readings" (voltage or wave form).

The sidetracking action of portable test equipment furnishes more accurate identification of the malfunctioning area than do the symptoms alone. The malfunctioning area or channel segment can now be isolated to a small number of parts—in the M-33 system to less than one per cent of the parts in the system or about two or three tubes and associated parts. This step is called block identification. The two or three tubes and associated parts are called a "trouble shooting block" or a channel segment, and the wave form which would be affected by a malfunction of any one of the parts within the block can be used to isolate the malfunction to this block.

Once the malfunction is localized to a trouble shooting block, how can the individual part within the trouble area be identified? Any trouble area consists of a number of parts, such as resistors, capacitors, and tubes. These parts are related in a sequential manner and, most important, they are all attached to tube pins. A tube usually has seven or nine pins or terminal points. Attached to each of these pins is a chain of from one to about six parts. These parts, acting together, produce a certain resistance (or voltage) reading at the tube pin. The resistances of chains can be made visible at the tube pins with portable test equipment (ohmmeter). Correct resistances are known for each terminal point. Hence, a measured change from the correct value indicates a malfunctioning part in the chain attached to that terminal point. This step is referred to as "tube chain" identification.

Once the malfunction is reduced to a short chain of parts, it is simple to locate the one part which is out of tolerance. Each part has a resistance value which changes (generally to zero or infinity) when the part malfunctions. Since the correct value for each part is known, a measured change from that value indicates a malfunction. This last step is called "part" identification. Sometimes the circuit attached to the tube pin is such that the resistance of the circuit will not change when a certain part in the circuit malfunctions. Under this condition all parts which are "hidden" in the tube pin circuits are tested individually.

[1] The analysis of the M-33 Track subsystem resulted in the isolation of about 24 channels. Selection of one channel from two dozen would limit the possibilities to 1/24 or about 4 per cent of the components in a subsystem. As all channels do not have the same number of parts in them, the figures used are averages.

To recapitulate, the four steps in identification are:
(1) Symptom to symptom area
(2) Symptom area to trouble shooting-block
(3) Block to tube chain
(4) Tube chain to individual part

These four steps are efficient isolators of malfunctions. When the steps are performed in this order, the greatest number of parts are eliminated from consideration in the shortest time. This does not mean that the steps must be taken in this order. In the extreme case the last step, measuring the resistance of each part, could be taken first. This eventually would lead to the correct identification of the malfunctioning part, but much time and effort would be required to measure each part rather than large groups of parts.

There is a characteristic of most electronic systems that can be utilized independently or as an integral part of other methods of trouble shooting, or it may be completely ignored. A new chassis can be substituted for one assumed to contain the malfunctioning part; if the assumption was correct, substitution of the new chassis causes the equipment to again function properly.

Signal flow channels and chains weave in and around the radar system; they go through many chassis. Some chassis have several channels going through them, and others have only portions of one channel. Chassis exist because of the obvious physical convenience of handling several small pieces of equipment rather than a single large one. Chassis are connected to the system through pressure contacts, so they may be removed from the equipment without time-consuming unsoldering of connections.

The characteristics that have been mentioned are the key elements of the electronic (radar) system. Certain symptoms are caused by any one of certain identified parts and no others. There are a sufficient number of these symptoms that the entire system may be divided into groups of parts that will produce one of these symptoms and no other. In like manner, there are mutually exclusive subgroups in each group, and each subgroup produces indications unique to the parts in that subgroup. Similarly, within each subgroup there are still further subdivisions and, finally, within them are single elements which consist of a throw-away part (e.g., resistor or capacitor).

Maintenance men have used symptoms and indications in their trouble shooting for years. However, a method has not been developed for systematically identifying each symptom cue and response action. The method of analysis described in this report clearly defines a way to trouble shoot. End-of-channel information is used first because it is immediately available from inspection of built-in indicator displays and effectively discriminates between good and bad channels. Sidetracking action by portable test equipment is generally used next, as each measurement checks a large group of parts. In the final steps, relatively short chains of parts and individual parts within the chain are measured by resistance meters. This sequence results in an efficient trouble shooting procedure which logically seems easy to follow, highly reliable, and economical of trouble shooting time.

Appendix B

SUPPORT MATERIALS[1]

Various lesson plans and student handouts have been referred to in the text. In this Appendix, brief descriptions and examples of those printed materials are provided.

TROUBLE SHOOTING BLOCK DIAGRAMS

Section 2 dealt with the analysis of a system into trouble shooting blocks. To make use of this information, a block diagram must be constructed. This block diagram appears similar to those in current use. However, current block diagrams can be used only for teaching system functioning at a block level. FORECAST-type block diagrams are used for this purpose and also are used during system trouble shooting. They can be used in this manner because the contents of each block have been specifically determined and defined on schematic diagrams in terms of individual parts contained within each block.

A FORECAST-type block diagram (see Figure B-1) shows in medium-width lines all the trouble shooting blocks of the system and the main signal flow between these blocks. In addition, the blocks are organized so that the block contents of chassis and subchassis can be determined. This is a type of location information which is very useful to the new repairman. In Figure B-1, for example, the heavy lines are subchassis boundaries and the names of these subchassis are given in small print. Main chassis boundaries are shown by dot-dash lines with the name of the chassis shown in large print.

Other things which are shown on the FORECAST-type block diagram include (1) the name of each block, (2) switches which deal with main signal flow, (3) all important display indicators, such as meters and A-Scopes, and (4) major (signal flow) feedback signal. These are shown in fine lines on Figure B-1.

The block diagram example in Figure B-1 does not show any adjustment information. Future FORECAST-type block diagrams will include information pertaining to the block locations of certain adjustments. This information can be presented by attaching the symbol for a screw driver adjustment to a trouble shooting block. However, the location of all adjustments should not be shown on the diagram. The diagram should contain only those adjustments which, if changed, will not affect the outputs of preceding blocks in the same signal channel. The rationale for this has been presented in Section 3, page 53.

There are a number of other things which could be placed on a block diagram, but if this were done the block diagram would become unduly cluttered and thus difficult to use. The FORECAST staff has considered

[1]A description of these and other FORECAST-type materials can be found in HumRRO Technical Report 63, *op. cit.*

PULSE SYNCHRONIZ

RF COUPLER

Scanner

Duplexer

HV

Magnetron

Target

Lens

LOBING GEN

ECHO

SAMPLE

Balanced Converter
Rcvr Mixer   AFC Mixer

Sig CC

AFC CC

Local Osc.

Tuning Drive

AFC

AFC Search Pulse   Osc Alternator   AFC Disc

To Acq Trigger Generator

RC

Mod

Trigger Gen

Transmitter Pulse

I.F. Pre-Amp

IF AMPLIFIER

I.F. Attan

I.F. Amp

I.F. Detect

To Azimuth

To Elevation

To Antenna Gearing

Main Drive

Up   Down   Left Right

HPSA 1 or 4

HP Servo Pre-Amp

Coupling

MAIN STAB FEEDBACK

ALIGNMENT VOLTAGE

LOBING REFERENCE SIGNAL

ANGLE DETECTOR

Lobing Ref Amp

Phase Detect

Balance Mod

400 CPS

To TFI

PULSE DEMODULATOR

500 yd Exp Sweep

Network Driver

Clear-out Pulse

Range Gate

Sine Wave Smooth

Sine Wave Detect

AGC

MGC   AGC

Av. Voltage 8V- or 8V+

Delay Demod

Non-Delay Demod

From TFI

100 yd Notch

Video & Notch Mixer

.22µs Delay

Video Amp

AUTO AID MAN SIGNAL

STORED RATE

From Acq. Slew Circuit (For Az. only)

Int Drive

Norm   Acq   Norm Acq

Man-Aid   Auto

Driving (Manual)
Alignment (Auto)

LPSA Es or As

LPSA Eh or Aw

Man-Aid   Auto   Man-Aid   Auto   Man-Aid

Coupling   Coupling

INT STAB FEEDBACK

ALIGNMENT VOLTAGE

AUTO AID MAN SIG

HANDWHEEL DRIVE

Rate Control   Hand-wheel Drive

400 CPS

Clutch Engaged in Aid & Auto

Aid   Man   Auto

To TFI

Range   Elev   Az

Range   Elev   Az

TRACK SWEEP GENERATOR

Exp Sweep Amp

Sweep Gen

Sweep Mixer

Amp & Dis-placer

Sel Sig   Norm

Norm   Off   Off   Sel Sig

Range   Elev   Az

LOBING AMPLIFIER

Square Wave Gen

Un-blank Mixer

Track Video Amp

Scope   Hor   Grid

Vert

TRACKING INDICATOR

Man   Aid   Auto

LOBING REFERENCE SIGNAL

AUTO AID MAN SIGNAL

TO AZIMUTH

AUTO AID MAN SIGNAL

1

Figure B-1

BLOCK DIAGRAM

PULSE SYNCHRONIZER

From MTI Sync

To Acq Trigger Generator

To Acq Carrier Generator

Subchassis boundaries
— · — · — Main chassis boundaries

RC

Mod

Trigger Gen

Pulse Sync

MTI Test Pulse

Transmitter Pulse

Pre-Knock Pulse

From Acq Range Computer

IF AMPLIFIER

I.F. Atten

I.F. Amp

I.F. Detect

TRACKING RANGE COMPUTER

Tracking Range Generator

Range Mark Gate

Range Mark Select

PULSE DEMODULATOR

Sine Wave Smooth

To TFI

500 yd Exp Sweep

Track Range Gate

To PI & TFI

Pip Select

To Acq Video & Mark Mixer

Net-work Driver

Clear-out Pulse

Sine Wave Detect

AGC

MGC+   AGC

Pip Gen

Acq-Trk Range Mark

Relay Amp

-28V   From Acq Slew Circuit

From Range Slew Circuit

Av. Voltage 8V+ at 8V+

Delay Demod

Non-Delay Demod

Pip Gate Gen

Range Gate

From TFI

100 yd Notch

Main Gate Gen

Phase Shifter

Slew Motor

Sensing Relays

Video & Notch Mixer

.22 s Delay

Video Amp

Sine Wave Gen

Range Motor

To TFI

TRACK SWEEP GENERATOR

Range

Elev

Range

Elev

Az

RANGE MODULATOR

Auto-Aid-Man Select

Disable

Man-Aid

Man-Aid

Exp Sweep Amp

Sweep Gen

Auto Relay

Auto

Auto

Sweep Mixer

Amp & Displacer

Sel Sig

Norm   Sel Sig

Norm   Off   Off

Elev

Range Balance Network

LP Servo Amp Rd

LP Servo Amp Rh

Coupling Network

Square Wave Gen

Elev

Man-Aid   Auto

Man   Aid   Auto

HANDWHEEL DRIVE

400 CPS

Track Video Amp

Scope

Un-blank Mixer

400 CPS

Range Balance Mod

Rate Control

Hand-wheel Drive

TRACKING INDICATOR

Clutch Engaged in Aid & Auto

Figure B-1

putting on block diagrams such information as check point locations, normal readings at check points, and all chassis, even though some of these chassis may be the exact duplicates of others. In the M-33, for example, there are three identical tracking indicators. On Figure B-1 only one of these is shown and the other two are indicated. It is the opinion of the FORECAST staff that such information should be located elsewhere. That is, it is more important to keep the block diagram legible than to include a vast amount of trouble shooting information on the diagram itself.

OVER-ALL SYSTEM UNDERSTANDING

In Section 3, the use of symptom information was described. This information is used to logically interpret where in the system the malfunction might be. To make such interpretations requires that the repairman have a clear understanding of how each trouble shooting block contributes to over-all system functioning. To facilitate the acquisition of this knowledge, a block-diagram description should be written for each section of the system. Figure B-2 presents a portion of such a lesson plan. The lesson plan can be written in quite general terms but it should contain the following information: (1) the function of each trouble shooting block, (2) where each signal of the system originates, (3) the purpose of each signal flow chain in the system, and (4) where each signal flows in terms of the trouble shooting blocks through which it passes.

SYMPTOM LESSON PLANS

Symptom lesson plans do not seem to be in use in present training programs although this information is presented, at the instructor's discretion, in practical exercises. The FORECAST materials are prepared to be presented in conference sessions as well as in practical exercises. Also, special lesson plans are prepared for each of the four categories of symptoms described in Section 3, page 54. These categories were (1) symptoms which appear on meters, (2) symptoms which appear on scopes, (3) control symptoms, or those which are related to the incorrect operation of the system, and (4) symptoms which, regardless of how they appear, indicate that something is misadjusted. Figure B-3 contains a section on scope symptoms taken from the FORECAST M-33 IFC training material. Notice that the symptoms are related to the trouble shooting blocks that could cause these symptoms.

Two classes of symptoms, scope and operational symptoms, can be fairly easily interpreted, once the function of the trouble shooting blocks is understood. The interpretation of meter symptoms is not as easy, primarily because it requires quite a bit of experience before the repairman can remember the various ways of interpreting meter readings. The FORECAST approach to this problem has been to prepare meter-symptom handouts (see Figure B-4) which can be used during trouble

Example From FORECAST M-33 IFC Block Diagram Lesson: Tracking Subsystem

LESSON PLAN

INSTRUCTIONAL UNIT: STORY.

TYPE: Conference.

TIME ALLOTTED: Fifteen (15) hours.

CLASS PRESENTED TO: Class as designated.

TOOLS, EQUIPMENT, AND MATERIALS: One (1) ea Slide Projector w/screen.
One (1) lined and one unlined Block Diagram per student and instructor.

PERSONNEL: None

INSTRUCTIONAL AIDS: Slide (transparent) of Block Diagram.

REFERENCES: None

STUDY ASSIGNMENTS: None

STUDENT UNIFORM AND EQUIPMENT: Uniform; as designated.
Equipment; None.

TROOP REQUIREMENTS: None

TRANSPORTATION REQUIREMENTS: None

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1. PRESENTATION.
   a. Introduction. (Conference, two minutes.)
      (1) Objective. The objective of this block of instruction is to have the students acquire familiarization with the general theory of how the Track subsystem of the M33 operates.
      (2) Standards. It is contemplated that, at the conclusion of this block of instruction, the student will understand the sequence of signal flow and the nature of component functioning within the track portion of the M33.
      (3) Reasons. All repairmen must be familiar with the signal flow between and functioning of areas of the Track subsystem in order to perform trouble shooting and repair on this equipment.
   b. Explanation. (Conference, eight hours.)
      (1) General.
         (a) The direction of signal flow in this Block Diagram is shown by arrow heads.
         (b) Description of Signal. The signals referred to in this Block Diagram are of many types, for example, pulse signals, gate signals, sine waves, target echoes, and DC voltage.

         NOTE: Instructor should depict these signals on the chalkboard for the students.

         (c) Size of blocks. The blocks discussed in this block of instruction may contain a single tube or several tubes. The tubes perform the functions which give the blocks their names. The block designation or name for a tube or group of tubes is for convenience and will describe a tube or group of tubes that performs a necessary function within the system.
         (d) Functions of blocks. The functions of the different blocks will fall largely within the categories of generating signals, delaying signals, amplifying signals, comparing different signals, mixing signals, shaping signals, and relaying signals. Any other function performed by blocks will be variations of the above. Any block may perform more than one function but this is the exception rather than the rule.
         (e) The signal flow within the system is generally over wires, which are depicted by solid lines between blocks. Signal flow may be radio frequency signals in one portion of the system, DC voltages in another, video in another and so forth. Any change in type of signal flow will be accomplished by a block. Mechanical connections are depicted by a dashed ($\cdot - \cdot$) line that means there is a mechanical linkage between the components so connected. You will notice that as lines move through the system there are slight humps in some lines as they cross other lines. This merely indicates that the lines do not connect at that point. Straight line connections indicate junctions of the wires represented by those lines.

(Continued)

Figure B-2

(2) Pulse Synchronizer.
    (a) Everything starts at the Pulse Synchronizer.
    (b) The Pulse Synchronizer gets its power signal from a power supply in the radar cabinet.
    (c) The Pulse Synchronizer generates a pulse signal 1000 times per second. (Student not told about the MTI synchronizer establishing the pulse rate until later when Acquisition system is presented.)
    (d) This signal triggers all activity within the Track system.
    (e) The signal from the Pulse Synchronizer goes to the Pre-Knock Pulse (ignore at present) and to the Transmitter Pulse.

(3) Transmitter Pulse.
    (a) The Transmitter Pulse delays each pulse from the Pulse Synchronizer before sending it to the Trigger Generator.
    (b) The signal remains the same but is delayed in the Transmitter Pulse. (1000 times per second.)
    (c) This delayed signal is then sent to the Trigger Generator.

(4) Trigger Generator.
    (a) The Trigger Generator amplifies (slightly) the signal from the Transmitter Pulse.
    (b) The Trigger Generator amplifies (increases the strength) the signal just enough to trigger the next block.
    (c) This amplified signal goes to the Modulator.

(5) Modulator.
    (a) The Modulator receives its signal from the Trigger Generator.
    (b) The Modulator amplifies this pulse signal about 100 times.
    (c) The Modulator sends this highly amplified pulse signal to the Magnetron.

(6) Magnetron.
    (a) The Magnetron receives its signal from the Modulator.
    (b) The Magnetron gives this pulse signal a radio frequency (RF) (which can be varied by adjustment) and transmits (or broadcasts) this frequency through the Wave Guide.

(7) Wave Guide.
    (a) The Wave Guide receives radio frequency waves from the Magnetron.
    (b) The Wave Guide is essentially a rectangular hollow tube which guides these radio frequency waves from the Magnetron to the lens of the tracking antenna and to the AFC Mixer.

(8) Lens (Tracking Antenna, outgoing waves).
    (a) The lens of the tracking antenna receives radio frequency waves through the Wave Guide.
    (b) The lens causes these radio frequency waves to be transmitted in a given direction.
    (c) The radio waves leaving the lens are transmitted into space.

(9) Target.
    (a) Radio frequency waves are transmitted into space by the antenna as described above.
    (b) If the waves hit NO targets, they are dissipated in space.
    (c) If the waves engage anything of density such as airplanes, smoke stacks, trees, clouds, snowfall or fog banks, they bounce off these dense bodies and at least some will bounce back to the lens of the antenna. These returning waves are called target echo.

(10) Lens (Tracking Antenna, incoming target echo).
    (a) A few of the target echoes will strike the lens (1000 times per second).
    (b) The lens deflects these target echoes through the Scanner (disregard at present) into the Wave Guide. The duplexer in the Wave Guide distinguishes the incoming from the outgoing signals and channels them in the appropriate directions.

(11) Wave Guide and Duplexer.
    (a) The target echoes are fed by the lens into the Wave Guide.
    (b) The duplexer, which is located in the Wave Guide, separates the incoming target echoes from the outgoing pulses and directs the target echoes into the Receiver Mixer.

(12) Receiver Mixer.
    (a) The Receiver Mixer receives a signal both from the Wave Guide and from the Local Oscillator.
    (b) The function of the Receiver Mixer is to mix the target echo and the signal from the Local Oscillator.
    (c) The signal from the Receiver Mixer goes to the IF Pre-Amp.

Figure B-2 (Continued)

Example From FORECAST M-33 IFC Scope Symptoms Lesson Plan: Tracking Subsystem

LESSON PLAN

INSTRUCTIONAL UNIT: SYMPTOMS.

TYPE: Conference.

TIME ALLOTTED: Six (6) hours.

CLASS PRESENTED TO: Class as designated.

TOOLS, EQUIPMENT, AND MATERIALS: One lined Block Diagram per student and instructor.

PERSONNEL: None

INSTRUCTIONAL AIDS: Chalkboard, w/chalk.

REFERENCES: None

STUDY ASSIGNMENTS: None

STUDENT UNIFORM AND EQUIPMENT: Uniform, as designated. Equipment, None.

TROOP REQUIREMENTS: None

TRANSPORTATION REQUIREMENTS: None

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1. PRESENTATION. (Conference, six hours.)
   a. Introduction. (Conference, three minutes.)
      (1) Objective. The objective of this period of instruction is to have the students acquire a knowledge of the symptoms presented by common M33 malfunctions.
      (2) Standards. The students should, at the conclusion of this period of instruction, be able to recognize and interpret all the symptoms discussed in this unit of instruction.
      (3) Reasons. The accurate interpretation of symptoms is the foundation for efficient and accurate trouble shooting.
   b. Explanation. (Conference, two hours.)
      (1) General. Symptoms are the manifestation of a malfunction. To appreciate symptoms properly, we must approach a malfunctioning M33 systematically. We must attempt to completely energize the system, to include scope intensities, and attempt to operate the set in Manual Aided and Automatic in all scope modes. We assume only one malfunction occurs at any given time.
      (2) Scope Symptoms. In the interpretation of scope symptoms, we should first determine what is missing from or wrong with the scopes. We should then determine how many scopes present this malfunction—one, two, or three. We should then find where a signal starts that could cause this malfunction to occur and we will find our malfunction between where it might be and where it is proven not to be.
         (a) Grass is to a scope what static is to a radio. It is fed into the system from between the Pulse Synchronizer to the IF Pre-Amp. There are many sources of grass and not all of them will malfunction at the same time; so, if we don't have grass on the scope, it is caused by a malfunction in some box passing the grass (IF Pre-Amp to Video Notch Mixer), not something generating the grass. If we don't have grass we will not have Target Echo.
         (b) Target Echo. If we can't get Target Echo on the face of the scope and we have grass, our malfunction then must be in some block behind the IF Pre-Amp.
         (c) 100 Yard Notch. If all three scopes are missing the 100 Yard Notch, it must be a malfunction in something generating or passing the 100 Yard Notch (not within the tracking indicator). If we have an Expanded Sweep on the face of the scopes we know that the Network Driver is receiving adequate signal. Our malfunction must be between the Network Driver and the Video and Notch Mixer. (The Video and Notch Mixer can pass Video and not pass the Notch signal.) If we have no 100 Yard Notch on one scope the malfunction must then be in the Track Video Amplifier, the only block dealing with vertical signals within a single tracking indicator.
         (d) Main Sweep.

(Continued)

Figure B-3

1) If we have no Main Sweep on any scope, the malfunction must be in the Pre-Knock Pulse or the Pulse Synchronizer. If the Magnetron will energize, we know it is Pre-Knock Pulse; contrarywise, if the Magnetron will not energize, we know our malfunction must be in the Pulse Synchronizer.
2) If we have no Main Sweep on one scope, our malfunction must be between the Sweep Generator and the Amplifier and Displacer.

(e) 500 Yard Expanded Sweep.
1) If we have no 500 Yard Expanded Sweep on three scopes, our malfunction must be between the 500 Yard Expanded Sweep and the Main Gate Generator. (Presence of Main Sweep tells us that Pre-Knock Pulse is functioning properly.)

NOTE: Explain at this point that the Acq-Trk Range Mark will not affect the presence or absence of the 500 Yard Expanded Sweep in any way.

2) If we have no 500 Yard Expanded Sweep, we will have no 100 Yard Notch and we won't be able to Auto Trk in Range. (The Network Driver will not be functioning.)
3) Absence of the 500 Yard Expanded Sweep on one scope indicates a malfunction in the Expanded Sweep Amplifier or the Sweep Mixer.

(f) Target Echo missing from the face of one scope. (Grass is present.) Our malfunctioning must be behind the IF Pre-Amp. Presence of Main Bang on the scope tells whether or not the Magnetron is working.

(g) No electronic cross indicates a malfunction between the Pip Gate Generator and the Acq-Trk Range Gate. No electronic cross and no 500 Yard Expanded Sweep indicates a malfunction in the Pip Selector or the Acq-Trk Range Gate. Absence of 500 Yard Expanded Sweep, but presence of electronic cross, means that the Pip Gate Generator and the Pip Selector are not stopping the electronic cross signal, but the Acq-Trk Range Gate may be.

(h) Absence of all vertical signals on all scopes indicates malfunction in the Video and Notch Mixer. It can pass Video and not pass the Notch signal, or the contrary may be true or it may pass neither Video nor Notch signal.

(i) Any distortion of vertical scope presentation of just one scope is caused by a malfunction in the Track Video Amplifier.

(j) Presence of one rather than two Target Echoes in NORMAL and SELECTED signal on both the Azimuth and Elevation scopes indicates a malfunction in the Lobing Generator. The same condition on only one scope indicates a malfunction in the Amplifier and Displacer.

(k) No light of any sort on one scope indicates that that scope is bad. (Or that the scope itself is malfunctioning.)

(3) Operational Symptoms.
(a) Failure to track in Manual in Range may be caused by a malfunction in one of the following blocks; Handwheel, Handwheel Drive, Coupling Network, Low Power Servo Amp R_h, Auto Relay, or motor.

(b) Failure to track in Aided in Range, Elevation, or Azimuth when the system will track manually, may be caused by a malfunction in the Rate Control, a connection between the Handwheel Drive and the Rate Control, or in the Coupling Network.

(c) Failure to track automatically in Range (range only), if the system will track in Manual and Aided, is caused by a malfunction in the Range Balance Modulator, Range Balance Network, Coupling Network, Low Power Servo Amp R_D, Auto Relay, or the motor.

(d) Failure to Auto Track in Range, Elevation, and Azimuth (Coast Disable switch in Coast position) is caused by a malfunction in the Network Driver, Range Gate, Non-Delay and Delay Modulator, or Auto-Aid-Man Selector.

(e) Failure to track manually in either Azimuth or Elevation is caused by a malfunction in the Handwheel, Handwheel Drive, Coupling Network, Low Power Servo Amp R_h, or Low Power Servo Amp A_h, Auto Relay, Intermediate Drive, Low Power Servo Pre-Amp, Low Power Servo Amp, Main Drive, or Antenna.

———————————————(Continued)———————————————

Figure B-3 (Continued)

(f) Failure to Auto Track in both Elevation and Azimuth is caused by a malfunction in the Sine Wave Detector, Sine Wave Smoother, or Lobing Generator.

(g) Failure to Auto Track in either Elevation or Azimuth (not both) is caused by a malfunction in the Lobing Reference Amplifier, Phase Detector, Balanced Modulator, or Auto Relay.

(h) Failure to continue tracking lost target is caused by a malfunction in the feedback chain.

2. APPLICATION. (Conference three and one half hours.)
Present symptoms and question students on what blocks could malfunction to cause that scope symptom to appear.

3. REVIEW. (Conference, one half hour.)
a. Clarify points of difficulty by asking students if they have any questions.
b. Summary.
(1) Review major symptoms.
(2) Reiterate important scope symptoms on one or three scopes.
c. Closing statement. The study of symptoms is the most important subject we have yet discussed. Accurate interpretations of the symptoms is the foundation for efficient trouble shooting.

Figure B-3 (Continued)

Meter and AFC Hunt Lamp Symptoms (M-33 Track)

HV (High Voltage) Meter

a. Normal readings: Magnetron current   - 6 (Adjustable)
                     Power Supply current - 45
                     Power Supply voltage - 8

b. Power Supply reading *high* in current, *low* in voltage — MAGNETRON or MODULATOR

c. Power Supply reading *low* in current, *high* in voltage — MAGNETRON, MODULATOR, TRIGGER GENERATOR, or TRANSMITTER PULSE.

d. Power Supply reading *high* in current and *low* in voltage *plus* a *zero* reading on the RC meter — MODULATOR.

RC (Reverse Current) Meter

a. Normal reading   - 6-10
b. *High* reading   - MAGNETRON or MODULATOR
c. *Low* reading (.0-4) - MODULATOR

AFC and Signal CC (Crystal Current) Meters

a. Normal reading for both - 0.5 to 2.0 (should be adjusted to 1.75).
b. AFC CC good and Sig CC bad - RECEIVER MIXER.
c. AFC CC bad and brief deflections every 10 seconds on Sig CC meter - AFC MIXER.
d. AFC CC bad and Sig CC bad - LOCAL OSCILLATOR or TUNNING DRIVE.
e. AFC CC bad and Sig CC bad except for brief deflections on both meters every 10 seconds - LOCAL OSCILLATOR, OSCILLATOR ALTERNATOR, or AFC DISCRIMINATOR.
f. AFC CC and Sig CC pegged high or reads zero - Bad TR tube in DUPLEXER.

AFC Hunt Lamp

a. AFC lamp changes sides every 10 seconds and doesn't begin to flicker within 60 seconds - AFC DISCRIMINATOR, OSCILLATOR ALTERNATOR, or LOCAL OSCILLATOR.
b. AFC lamp completely out or remains lit on one side for more than 60 seconds - AFC SEARCH PULSE or OSCILLATOR ALTERNATOR.

NOTES:

a. Check HV meter before checking RC meter.
b. When malfunction is isolated to either the magnetron or the modulator, use dummy load to check out modulator.

Figure B-4

shooting. These handouts list the correct readings for each meter and also the various blocks that could contain a fault if particular patterns of incorrect meter readings are obtained.

Adjustment symptoms may also be difficult to remember. Figure B-5 shows a portion of a FORECAST-devised adjustment handout for the M-33 IFC system. This handout contains most of the information needed to interpret adjustment symptoms or to make adjustments. The newer military adjustment manuals present adjustment information in a somewhat similar fashion, and therefore special adjustment handouts may not be required.

TECHNICAL MANUALS OF SCHEMATIC DIAGRAMS

One of the primary purposes of organizing a system into trouble shooting blocks is so that the repairman can readily determine what parts he is checking at a particular point. This information is originally obtained from an analysis of manuals containing schematic diagrams. The information is communicated to the repairman through simple modifications of these same manuals. These modifications consist of taking each schematic diagram and drawing lines around those parts that constitute a particular trouble shooting block. Figure 11 shows an example of how this is done. Of course, it is time-consuming to go through many manuals drawing lines around certain parts. Actually, this should be done before the manuals are printed in final form. In this way block boundaries would be just one of the many items of information printed on a schematic diagram.

It can be seen from Figure 11 that drawing block boundaries on the usual type of schematic diagram may have the result that the parts of one particular block are scattered over much of the diagram. This problem could be partially handled by redrawing the schematic diagram. It is possible, also, to have a separate diagram for each trouble shooting block. This latter procedure has been tried in a FORECAST pilot study, but it was not as effective as the procedure of drawing block boundaries on existing military schematic diagrams. This was because of the difficulty in seeing the relations among the various blocks located on the same chassis when the diagrams of these blocks appeared on separate pages. Then, too, common parts must be shown on more than one diagram when individual block pages are used. Therefore, the best procedure seems to be to use the present type of chassis schematic diagram, but redrawn to show the parts of each block grouped closely together within printed block boundaries.

There are oth items of information which could appear on a schematic diagram; for example, a list of the parts common to more than one block, and the location of block check points.

M-33 Track System Adjustments*

Tracking Antenna

I Adj. No.	II Name of Adjustment	III Chassis	IV Reason for Making Check or Adjustment**	V Test Equipment	VI Location of Display	VII Adjustment Procedure***	VIII Correct Display
	Magnetron tuning	RF Coupler	After installing new magnetron; or when the dial on tuning drive does not line up with the dial on the mag.	Screw driver	Mag. tuning drive dial and mag. dial (inside mag. housing)	Remove magnetron blower housing. With the Frequency decrease switch S2, set the dial on the tuning drive to read "7." Disconnect the tuning drive cable from the tuning drive. Use screw driver to adjust magnetron dial until you reach the "stop." Stop reached just before the number "7" flips into the window of the dial on the magnetron.	Index marker and circular dial both read "7."
	Search Time Adjust R39	AFC	After installing new magnetron or local oscillator; or if the full search cycle takes longer than 18 ±2 seconds.	Screw driver; watch with second hand	AFC indicator light (neon lamp)	Adjust R39 with screw driver until AFC light stays lit for 9 ±1 seconds on each side.	Full search cycle (both sides) of 18 ±2 seconds.
	Bias Control R36	AFC	After installing new V4 or V8 in AFC. Once made, adjustment will not vary until a new component is put into the system.	Screw driver; DC Voltmeter (TS 352)	Voltmeter (TS 352)	Disconnect plug from J2. Set TS 352 to 20,000 ohms/volt scale and measure between J2 and chassis ground.	±19 volts when the dim electrode of AFC lamp is lit.

* Other than routine preventive maintenance checks and adjustments.
** Other than routine preventive maintenance. Reason will generally be the installation of new components or because of a noticed mis-adjustment. Where reason mentioned is the replacement of a tube or major components, the adjustment is usually also made after replacement of the other associated parts of the circuit.
*** Return test switches, lead-ins, and the like to normal operating position after completing the adjustment.

Figure B-5

ACKNOWLEDGMENTS